OVERCOMING HURDLES IMPLEMENTING MULTI-

SKILLING POLICIES

THESIS

Joshua M. Isom, Captain, USAF

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AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

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Joshua M. Isom, BS

Captain, USAF

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Joshua M. Isom, BS
Captain, USAF

Committee Membership:

Dr. A. W. Johnson
Chair

Dr. K. L. Schultz
Member

AFIT-ENS-MS-15-M-124

Abstract

Ogden ALC at Hill AFB has been authorized to promote wage grade employees if they are multi-skilled, but that authorization will expire at the end of Fiscal Year 2018. Simulation research by Capt Wesley Sheppard demonstrated significant cost savings/cost avoidance if multi-skilling is pursued, but there are significant challenges to implementation. This research examined two challenges in implementation. First, how many employees can be multi-skilled and still maintain proficiency in both skills? Second, once multi-skilled, is there a technique that can be applied to easily and effectively schedule the new multi-skilled workforce. Using linear programming, staffing numbers were calculated based on current manning and a minimum time policy to ensure the multi-skilled workforce has the opportunity to perform both skills. These calculations were based on a variety of inputs, such as output per man day (OPMD), different minimum time policies, an estimated lower bound, average, and upper bound for the annual workload, etc. Scheduling theory was applied to give schedulers and front line supervisors an easy to use heuristic that can make a significant difference in the amount of time it takes to complete a set of tasks. Various scheduling heuristics were applied to give supervisors an effective way to schedule the workforce.

Acknowledgments

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Joshua M. Isom

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I. Introduction

Background

Employing a multi-skilled workforce can provide the employer flexibility to accomplish their mission. Captain Wesley Sheppard demonstrated the benefits of multi-skilling in a simulation environment by modeling the F-22 Heavy Maintenance Modification Program at Ogden Air Logistics Complex (OO-ALC). Sheppard tested how multi-skilling the workforce would affect projected employee labor rates, employee utilization, and aircraft throughput. The thesis concluded that all three of these measures will benefit from skills pairing, and then identified several promising pairings to achieve these benefits (Sheppard, 2014).

Sheppard (2014) modeled Ogden ALC's F-22 Maintenance Program because Ogden ALC was the Air Force's multi-trade demonstration project location. The 2004 National Defense Authorization Act (NDAA) directed the Secretary of the Navy to carry out a demonstration project (108th Congress, 2003). The NDAA authorized the Naval Aviation Depots to promote workers certified in multiple trades at the journeyman level by one pay grade. That authorization expanded to include the Air Force and Army in the 2008 National Defense Authorization Act (110th Congress, 2007), originally authorized until fiscal year 2013 but extended to the end of fiscal year 2018 in the 2013 National Defense Authorization Act (112th Congress, 2012).

So far, multi-skilling the workforce at Ogden ALC has not happened despite authorization to do so. Sheppard demonstrated that multi-skilling the workforce at Ogden ALC could achieve significant cost savings. This research's intent is to add to that work by focusing on the primary implementation hurdles that will arise in multi-skilling the F-22 Heavy Maintenance Modification Program. The goal is to contribute something that the customer, Ogden ALC, can use to help in implementing the multi-skilled workforce. The deadline to implement multi-skilling is fiscal year 2018. However, every day that passes is potential cost savings lost by not multi-skilling the workforce and gaining that employer flexibility.

The feasibility of multi-skilling seems like an easy problem to solve, and it is if you disregard proficiency. A leader in an organization can multi-skill his entire workforce. However, the workforce will not be an effective workforce if there is not enough opportunity to remain proficient. The mistake of disregarding proficiency and blindly implementing multi-skilling could be extremely costly to an organization. Making your Skill A employee a Multi-skill A/B employee takes time and money. Training, certifications, wages of the employee, and overtime wages to those making up for lost output by the trainee can add up to thousands of dollars. That money could be money well spent if it increases the flexibility and productivity of your organization. However, if you overdo the multi-skilling policy, it can be a costly mistake.

Research Focus

Research will focus on staffing decisions and scheduling. The research expects that staffing will be a significant hurdle in implementation, especially when you consider proficiency. Additionally, scheduling will be difficult as well. A multi-skilled workforce increases the complexity of scheduling. Many journal articles discuss the complexity of scheduling a multi-skilled workforce. The objectives of an organization further compound the complexity of scheduling. Each journal article attempts to solve a specific scheduling problem for a specific objective. This research will focus on solving a specific scheduling problem for Ogden ALC to meet their objective.

Problem Statement

Multi-skilling the workforce at Ogden Air Logistics Complex has the potential to reduce employee labor rates, increase employee utilization, and reduce the number of days required to flow an aircraft through required maintenance milestones. This opportunity will be lost if the National Defense Authorization Act that authorizes a multi-skilled workforce (Currently 2013 NDAA authorizing action through fiscal year 2018) expires before actions are taken to implement. We must answer difficult questions before implementation. These questions include “How many employees can you multi-skill and maintain a minimum level of proficiency?” and “Once multi-skilled, is there any technique to scheduling the multi-skilled workforce?” Addressing these questions should provide Ogden ALC the information needed to take the next step and implement multi-skilling.

Research Objectives and Questions

Research Question 1: How many employees can you multi-skill and maintain a minimum level of proficiency?

Research Question 2: Once multi-skilled, is there any technique to scheduling the multi-skilled workforce?

Chapter II will communicate important concepts found in the literature on skill proficiency topics. These topics include skill acquisition, skill transfer, skill retention, and skill loss. Chapter III will document the methodology used to address the two research questions. Chapter IV provides the results received when the linear programming and scheduling theory heuristics are accomplished. Finally, Chapter V synthesizes those results from Chapter IV and provides a conclusion and recommendations.

II. Literature Review

Chapter Overview

The review of literature for this study starts with the original thesis by Capt Sheppard. The literature review will expand to explore research conducted on proficiency and skills, specifically research that examines skills retention and techniques that mitigate skills loss.

Capt Sheppard's Thesis

Captain Wesley Sheppard's research into multi-skilling the workforce formed the foundation of my research. Sheppard's work was the start of a multi-skilling research effort conducted by AFIT for Hill Air Force Base's F-22 maintenance depot. The conclusions were key to proceed with this research.

The first key conclusion used in this research was which maintenance specialties to pair via multi-skilling. Capt Sheppard recommended pairing Low Observable with Sheet Metal, Aircraft Mechanics with Aircraft Electricians, and Fuels Technicians with Avionics Technicians (Sheppard, 2014:104). These six skills account for 97 percent of all man-hour requirements for maintenance on aircraft. In addition to accounting for a majority of the man-hour requirements, these six skills perform critical path tasks, and therefore efficiencies applied on these tasks will reduce overall completion time. The pairings were determined based on several considerations. Capt Sheppard considered utilization rates, man-hour requirements, as well as size when determining the skill pairings. Given these considerations, he formed a hypothesis on which skills would pair well together, and then performed an experiment using Arena simulation software. Alternative skill pairings were examined in the experiment, but none yielded better results than Low Observable paired with Sheet Metal, Aircraft Mechanic with Aircraft Electrician, and Fuels Technician with Avionics Technician.

A second key conclusion Capt Sheppard discovered was the benefits of multi-skilling when applied to the F-22 maintenance depot at Hill Air Force Base. There is no shortage of multi-skilling literature, but the literature typically presents results on a specific environment. When the inputs change, the results may change. Capt Sheppard demonstrated the benefits of multi-skilling using specific inputs from the environment at Hill AFB. Those benefits, utilizing inputs based on 2013 data, are expected to be 1.1 million dollars in cost savings/avoidance when utilizing a multi-skilling policy compared to an overtime policy to achieve flow day target goals (Sheppard, 2014:92). When estimates are applied based on a future doubling of workload, expected cost savings/avoidance totals 1.6 million dollars (Sheppard, 2014:102). These calculations are based on an assumption that employees maintain 100% efficiency in both skills, but further research concluded that efficiency can drop to 95% efficiency (indicating 5% longer processing times), before overtime policies outperform multi-skilling policies.

Examples of Military Multi-skilling Efforts

The US Air Force has undergone several multi-skilling efforts to increase the flexibility and utilization of its workforce. In the 1980s, the Air Force initiated a merger/multi-skilling effort called “Project Rivet Workforce”. At the time, the Air Force faced budgetary constraints and had difficulty maintaining the high required manpower levels. The Air Force had 134 specialized maintenance career fields, many of which would have a low utilization rate due to the specialization. The Air Force combined many of these specialized maintenance career fields based on the similar technology career fields (Elliot, 1988:4). In 2002, Supply, Transportation, and Logistics Plans were combined into the Logistics Readiness Officer career field (Lewis, 2005:2). In 2005, Personnel and Manpower career fields combined into Manpower-Personnel career field (O'Neill, 2012:3). Then in 2008, the Manpower-Personnel career field was combined with the Services career field into the Force Support career field (O'Neill, 2012:4). These are just a few examples of multi-skilling that the Air Force has undergone. The career fields vary greatly, but they were all merged for one common purpose: flexibility.

Skills Acquisition and Skills Transfer

Before we look at skills decay and retention, we should first explore skills acquisition and skills transfer. This will be the first experience a new trainee has with the skill, and that experience can have considerable effects on how the skill is retained in the long-term. Skills transfer is the "effective and continuous application of knowledge and skills learned in training once back on the job" (Schindler, 2012:10). It has been estimated that transfer rates can be as low as 10 to 20%, indicating that skills learned in training are not being retained.

There are three factors that impact skills transfer: Trainee Characteristics, Training Design, and Work Environment (Baldwin and Ford, 1988:64-66). A model of the transfer process is displayed in Figure 1. The model is best described from right to left. For a skill to transfer through generalization and maintenance, a skill must be first learned and retained (link 6). Trainee characteristics and work environment have a direct effect on skills transfer (links 4 and 5), and an indirect effect on skills transfer through the learning and retention phase of the model. Training design has an indirect effect on skills transfer through the learning and retention phase of the model as well.

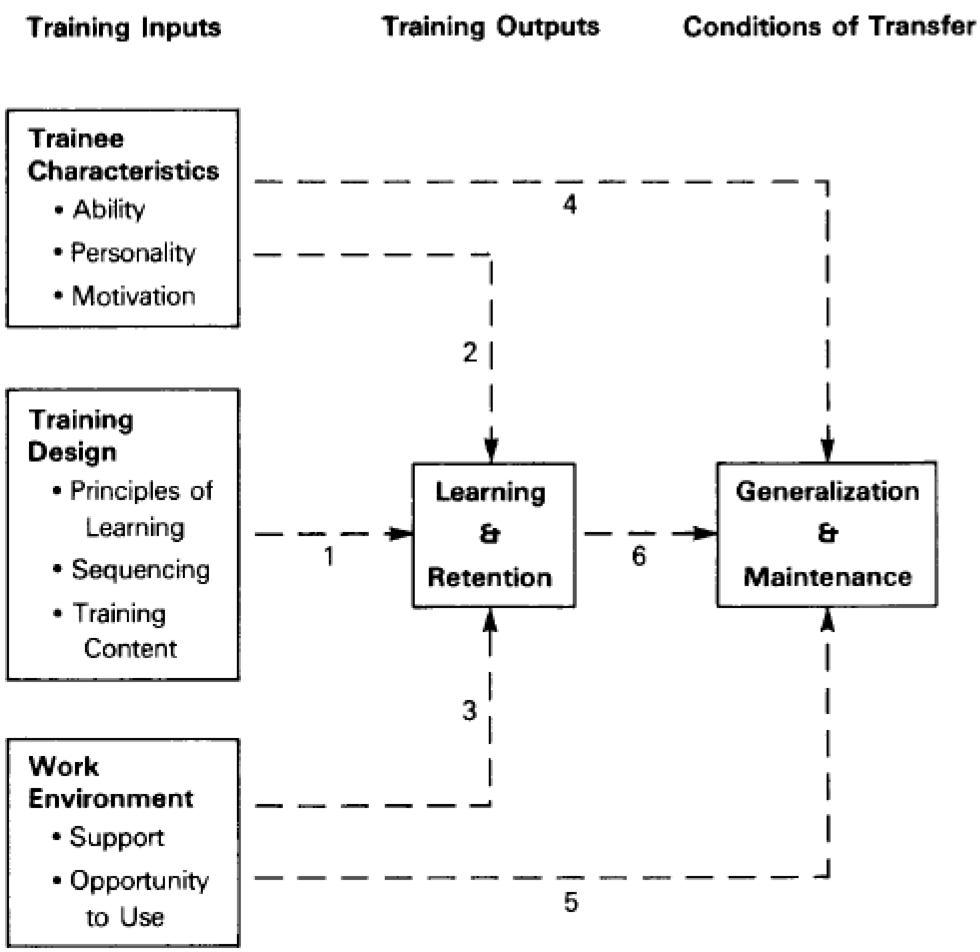

Figure 1: A Model of the Transfer Process, Baldwin and Ford

Trainee characteristics can affect skills transfer, both directly on the transfer process as well as indirectly by affecting learning and retention. Through employee ability, personality, and motivation, an employee is able to learn and retain skills during training, and those skills learned increase the success of being transferred to actual applications on the job.

Work Environment will have an effect on skills transfer as well. Work environment consists of both workplace climate and peer support (Martin, 2010:88). Work environment is an individual's perception of supervisor support, opportunity to use new training, level of peer support, supervisor sanctions, and positive or negative personal outcomes resulting from application of training on the job (Hatala and Fleming, 2007:4). Peer support is the support trainees receive from others in the organization. This support can come from coworkers, supervisors, and managers. Harry J. Martin conducted a study of the effects of these variables on skills transfer and reached several conclusions (Martin, 2010:96). First, both workplace climate and peer support are related. A favorable workplace climate contributes to higher peer support. Second, both workplace climate and peer support produce a positive effect on skills transfer. Peer support produced a much larger effect than workplace climate, but both should be considered to contribute to a more successful skills transfer. The author proposes that support should be given to trainees before, during, and after training. One method that the author used to encourage peer support was a peer meeting (Martin, 2010:94). This meeting was conducted 2 to 12 weeks after training, at which point the managers-in-training from the study came together to discuss how their efforts post-training were going. Their peers in the meeting provided encouragement and feedback based on the discussion, and this peer support aided in the skills transfer.

Training design focuses on how the training is delivered to the trainee. There are training methods that might improve learning and retention during the acquisition phase.

The active interlock modeling (AIM) protocol is a dyadic training method that has been calculated to be 100 percent more efficient than traditional individual training methods (Arthur et al., 1997:785). In the AIM-dyad protocol, trainees are paired together in training to accomplish tasks. One trainee controls half of a complex task, and the other trainee controls the other half of a complex task. Without increasing the training time, trainees trained using the AIM-dyad protocol achieve the same performance as trainees trained using a traditional individual training protocol, despite only having half the hands-on experience. AIM-dyad training protocol alone has no noticeable benefit to skill retention, but skill loss of the AIM-dyad protocol is comparable to individual training protocols.

By halving the training time per trainee, it presents an opportunity to overlearn the employee. Arthur claims "the single most important determinant of both skill and knowledge retention appears to be the amount or degree of overlearning" (Arthur, 1998:59). Overlearning is additional training, above and beyond what is needed for initial proficiency. It is believed that overlearning decreases skill decay due to a strengthened bond between stimulus and response, increased repetitions providing more feedback to trainee, decreased concentrated effort of the trainee and increased automaticity, and increases the confidence in the trainee.

A study performed for US Special Operations Command (USSOCOM) examined the effects of overlearning on language retention and proficiency of Special Operations Forces. There were two groupings of SOF operators. Category I/II grouping were easier to learn languages, and category III/IV were more difficult to learn languages. Defense Language Proficiency Test (DLPT) scores were examined from 2004-2012. SOF operators were tested four times: Initial Acquisition Training (IAT), and three periods after IAT. Retention period 1 occurred on average 80-84 weeks after IAT, Retention period 2 was 142-143 weeks after IAT, and Retention period 3 was 196 weeks after IAT. In category I/II, those who trained in their language for 18 weeks outperformed the retention of those who trained for 14 weeks, in every time period except for the third retention period where the scores were the same (SWA Consulting, Inc., 2012:31-32). In category III/IV, a similar pattern of retention was observed. 24 weeks of language training in category III/IV outperformed retention of those who had 20 weeks of language training in every time period, with diminishing differences up until the last time period 196 weeks after IAT (SWA Consulting, Inc., 2012:32). In summary, overlearning in this study observed a substantial difference in retention after initial training, but the difference in retention became negligible after 196 weeks.

Driskell, Willis, and Copper (1992) also looked at effects of overlearning on skills retention. The authors examined the effects of overlearning degree, retention interval, and type of task (physical or cognitive) on skills retention (Driskell et al., 1992:616). They conducted a meta-analysis of 15 studies that contained 88 hypothesis tests with 3771 test subjects. Each hypothesis test was coded with the type of statistical test, the sample size, effect size, type of task (physical or cognitive), degrees of overlearning, and the retention interval. A correlation coefficient, r, is used to measure effect size. An r value of $r = 0.1$ is a small effect, $r = 0.3$ is a medium effect, and $r = 0.5$ is a large effect. The authors make several conclusions regarding overlearning and skills retention. First, overlearning has an overall medium effect on retention ($r = .298$) (Driskell et al., 1992:618). Second, the type of task has varying levels of response to overlearning and skills retention, with overlearning having a medium to large effect on cognitive task skill retention (r = 0.216), and a small to moderate effect on physical tasks (r = 0.352) (Driskell et al., 1992:618). Third, as the degrees of overlearning increases, skills retention is increased. With 50 percent overlearning, there is a small effect on retention. At 150 percent overlearning, there is a large effect on retention (Driskell et al., 1992:619). Fourth, the impact retention period has on skills retention with physical tasks was positively correlated (i.e. as the retention period increased, so did the skills retention). The author suspects that subjects in the tests "cheated", or practiced their skills during the retention period. This might be viewed as a tainting of the results, but it can also be viewed as useful information as well. Employees should practice their skills whenever possible to maintain the retention of their skills, as confirmed by the r = 0.465 (Driskell et al., 1992:619).

Schendel and Hagman (1982) looked at the effects of overlearning and refresher training on skills retention. The authors performed a study of 38 Army reservists disassembling and assembling an M60 machinegun, measuring the effects of training on skill retention. The 38 Army reservists were placed into three groups: a control group which received a standard amount of training, an overlearning group which received twice as much training as the control group immediately, and a refresher group which received the standard amount of training initially and then a second set of training conducted four weeks later. All three groups were tested at the end of eight weeks for retention. The overlearning group did the best during testing for retention, performing 65 percent better than the control group. The refresher group performed nearly as well, 57 percent better than the control group (Schendel and Hagman, 1982:7). The research concludes that since overlearning can perform as effectively refresher training, the costs and risks associated with refresher training can be reduced or eliminated by adopting an overlearning training policy (Schendel and Hagman, 1982:14).

Hurlock and Montague (1982) summarize research findings conducted for the US Navy. The authors identified a relationship between feedback during training and retention as well as test taking and retention (Hurlock and Montague, 1982:6-7). Both of these methods serve to help trainees learn what is right and what is wrong. Feedback is typically present during formal initial skills training but is often lacking during on-the-job training. This presents an opportunity to support skills transfer and retention by ensuring that feedback is given often during on-the-job training.

Moderators of Skill Decay

Arthur (1998) investigated moderators of skill decay. A meta-analysis of 270 articles concerning skill degradation was conducted to provide quantitative data on degree of skill loss, and degrees to which skill decay is moderated by factors such as closed-looped versus open-looped tasks, physical versus cognitive tasks, natural versus artificial tasks, and speed versus accuracy tasks. There were some interesting conclusions of importance to the multi-skilling project. First, the paper demonstrated that after 365 days of non-use of a skill, the average participant performed the skill at a proficiency loss of around 10.97% (Arthur, et al., 1998: 77). This was based on all 178 data points from 52 articles that met inclusion criteria. Very different types of tasks were aggregated to produce the 10.97% figure. There are moderators to consider in skill decay that are further analyzed in the paper. Closed-loop/open-looped, physical/cognitive, and natural/artificial are all moderators of skill decay.

Closed-loop tasks are tasks that involve discrete responses and have a beginning and end. Open-loop tasks are tasks that are continuous responses and do not have a beginning or end. Tasks conducted at Ogden ALC are closed-loop: remove this panel, install this component, etc. The author originally hypothesized that open-looped tasks would experience less decay than closed-loop, because their indefinite nature allows for repeated practice (overlearning); however, their findings discovered that closed-loop tasks deteriorate at a lower rate (Arthur, et al., 1998: 80).

Physical tasks are tasks that require muscular strength or exertion of forces to perform. Cognitive tasks are mental tasks that could include problem solving and decision-making. Tasks at Ogden ALC should be classified as physical tasks. In the absence of mental rehearsal (practicing a physical or cognitive task in your head), the authors hypothesized that physical tasks would decay at a lower rate. Their hypothesis was confirmed in their meta-analysis, physical tasks deteriorate at a slower rate than cognitive tasks (Arthur, et al., 1998: 80).

Natural tasks are the tasks accomplished at any organization. The tasks at Ogden ALC are natural tasks. With natural tasks, the individual is generally more motivated to learn the skill and maintain proficiency. Artificial tasks are those that are created to simulate and experiment with, such as tracking, mazes, etc.   The authors hypothesize that natural tasks would deteriorate at a slower rate than artificial, and this hypothesis was confirmed (Arthur, et al., 1998: 81).

Linear Programming

Linear programming is a technique to solve optimization problems with linear objective functions and linear constraints (Ragsdale, 2008:21). The goal is to help people make good decisions. Ragsdale provides five reasons why linear programming and mathematical models are useful (Ragsdale, 2008:3-4).

1) Models are usually simplified versions of the object or decision problem they represent
2) Models are often less expensive to analyze decision problems
3) Models deliver needed information on a more timely basis.
4) Models frequently help examine things that would be impossible to do so in reality
5) Models allow us to gain insight and understanding about the object or decision problem under investigation.

There are four assumptions that must be met to qualify as a linear program: Proportionality, additivity, divisibility, and certainty (Lewis, 2008:5-6). Proportionality means that the contribution for any variable is proportional (i.e. no exponents, no roots, etc). Additivity means that any variable's contribution to constraints and objective functions are independent of other variables. Divisibility means that decision variables can take on partial values. Certainty means that all parameters (coefficients) are known with certainty.

Scheduling Theory

Scheduling theory is a decision-making process used to allocate resources to tasks over a given time period, with a goal of optimizing one or more objectives (Pinedo, 2012:1). Resources, referred to as machines in scheduling theory, are the tools used to complete the tasks. Resources can be actual machines on a shop floor, processors of a computer, runways at an airport, or employees. Resources can accomplish tasks at the same speed, or some resources can be faster or slower. Resources can have restrictions on what tasks they can accomplish. For example, if your resource is runways, a 6,000 ft runway may only accommodate aircraft up to 200,000 lbs. Tasks, referred to as jobs in scheduling theory, can have different priorities (weights), or they can have an earliest possible starting time or due date. Objectives are the goals determined by the decision maker. The objective could be to complete all jobs as quickly as possible (Makespan, or C_{max}), minimize the tardiness of the most late job (Maximum Lateness, or L_{max}), or it could be to complete the higher priority jobs as early as possible (Total Weighted Completion Time, or $\sum w_j C_j$).

There are two classes of scheduling theory problems. There are problems that are easy to solve, known as polynomial time problems or *P*, and there are problems that are hard to solve known as non-deterministic polynomial time problems, or *NP*-hard problems. Polynomial time problems are problems that can be optimally solved using an algorithm or scheduling rule. For example, if you have a single machine, and your objective is to minimize the tardiness of the most late job, the Earliest Due Date rule is optimal. Earliest Due Date tells you to schedule the job with earliest due date first, then the next earliest due date job second, until all jobs have been scheduled. *NP*-hard problems cannot be solved optimally in all cases using an algorithm or rule. The optimal solution may vary problem to problem, and therefore the only way to guarantee an optimal solution is to run every possible combination of machine, task, and time slot. However, heuristics or scheduling rules may provide “good enough” solutions that can get close to an optimal solution in a much quicker time.

There are some common scheduling rules that exist in scheduling theory. These rules may achieve optimality in certain *P* scheduling problems, or they might be tested on *NP*-hard scheduling problems to get an acceptable solution. As previously identified, Earliest Due Date (EDD) is a scheduling rule that is optimal in a single machine environment with an L_{max} objective. Shortest Processing Time first (SPT) is a rule where the job with the shortest processing time is processed first, and then the next shortest processing time is processed second, etc, until all jobs are completed. Longest Processing Time first (LPT) is similar to SPT but the longest processing time is scheduled first. Least Flexible Job (LFJ) is another rule that is optimal when you have two machines that operate at similar speeds, the processing time of all jobs is the same, there are restrictions on what machine can process which jobs, and the objective is to complete all jobs as quickly as possible. LFJ requires that you assign a job to your first machine based on the “least flexible” job that machine can process. Least flexible is defined as the job that can be processed by the smallest number of machines. For example, if job 1 can be processed by 8 machines, and job 2 can only be processed by 2 machines, then job 2 is the least flexible job and should be processed immediately by the first machine that can process it.

III. Methodology

Chapter Overview

This chapter is separated into two different sections. The first section will provide the methodology for answering the first research question, “How many employees can you multi-skill and maintain a minimum level of proficiency?” The second section will provide the methodology to answer the second research question, “Once multi-skilled, is there any technique to scheduling the multi-skilled workforce?”

The Data

The data was gathered from the Programmed Depot Maintenance Scheduling System (PDMSS). The data set comprises 106 aircraft inducted from 2007 to present. Data fields consist of: Serial Number, Weapon ID, Operation Number, Description of Operation, Major Job, Skill, Standard Hours, Actual Hours, Status Change Date, Status Code, and several other fields. There are 185,499 unique records in the data set, representing 185,499 tasks performed on aircraft.

One hundred percent of all aircraft operations data from PDMSS was exported into excel to maintain the data set. After excel was populated with the data, the data was then pruned to keep relevant and useful data for this research. The Skill Code field indicates the skill required to accomplish the operation of that record. This research focuses on Low Observable (AP), Sheet Metal (AS), General Mechanic (AG), Electrician (AR), Avionics (AC and AD), and Fuels Technicians (AT and AF), therefore all other skills were removed from the data set. Additionally, the Status Code indicates deleted or completed for an operation. For every operation that indicated deleted (8 in Status Code field), that record was removed from the data set. Status Code ‘8’ operations were added to the aircraft but were not needed.

After the data was pruned to remove irrelevant records, the data was organized by calendar year. Operations that were completed in calendar year 2007 were placed into a CY07 worksheet in excel, operations completed in calendar year 2008 were placed into a CY08 worksheet, etc. Once organized by calendar year, standard hours per skill code were added together to create a summary table, shown below.

Table 1: Standard Hours by CY

STANDARD HOURS									
	CY07	CY08	CY09	CY10	CY11	CY12	CY13	CY14	CY15 (to date)
AC/AD	742.9	1787.1	2215.2	2787.6	2641.2	2242.6	3040.7	2848.9	39
AT/AF	4523.5	5821.2	5513.4	5645.9	6318.9	6674.6	8276.3	6836.3	21.7
AG	6864.9	23610.1	13112.6	17644.5	16117.4	12487.2	14188.6	9967.4	14
AR	5774	5837.6	5915.6	8253.8	6106.9	7050.5	9431.5	5517.4	11.1
AP	22751.1	70615.8	94766.4	130212.3	113546.3	84133.3	108340.2	99885.3	794.4
AS	4557.8	20975.2	43775.3	58000.3	39796.1	33269.8	41145.1	31892.6	34.5

Calendar year 13 data was used to mirror Sheppard’s work. To estimate the “Future State”, where there is 13 maintenance docks, the researcher looked at average hours per maintenance dock per year for CY10 – CY13. CY10 – CY13 appeared to be similar in nature. Each year reached a maximum of 7 work in progress (WIP), with an average WIP ranging from 5.47 to 6.13. The hours per skill per year is comparable as well. Average hours/dock/year was used to estimate a lower bound, average bound, and upper bound for the “Future State” workload. For the lower bound, the minimum average hours/dock/year between 2010 and 2013 was multiplied by 13. The lower bound here represents the annual workload if every dock had the minimal amount of annual workload, based on historical data. The average bound was calculated by averaging the average hours/dock/year between 2010 and 2013, and then multiplied by 13. The average bound represents the annual workload if every dock had an average amount of annual workload, based on historical data. Finally, an upper bound was calculated by taking the maximum average hours/dock/year between 2010 and 2013 and multiplied by 13. The upper bound represents the annual workload if every dock had the maximum amount of annual workload, based on historical data. These values can be found in Table 3 and Table 4.

Research Question #1

The research question, "How many employees can you multi-skill and maintain a minimum level of proficiency?" is an important question to answer. Overdoing it can result in wasted money by training an employee in a second skill when there is not the opportunity to perform that skill. Even if it appears that the opportunity exists, is there enough opportunity to remain proficient? That is a difficult question to answer. As Capt Sheppard calculated in his research, an employee can fall to 95 percent proficiency in any of their two skills and still outperform an overtime policy in terms of cost (Sheppard, 2014:105). Below 95 percent proficiency, and then it appears that overtime policy may be the better cost effective solution to maintain throughput. How can we work towards no more than 5% proficiency loss, to ensure that the multi-skilling policy outperforms the overtime policy? Techniques identified in Chapter 2 will help. One way to decrease the proficiency loss is by overlearning. Another way to mitigate the proficiency loss is by performing the skill frequently. How often they should perform the skill will be a management decision. That leads the researcher to answering the first question.

A linear program has the ability to solve complicated mathematical problems much quicker than alternative methods. We need to define decision variables, an objective function, and our constraints. Decision variables are the variables of interest that we wish to solve in a mathematical model, and they will be represented with the symbols X_1, X_2, …., X_n. Our decision variables will be the number of employees to meet annual workload demand in our six skills and their paired multi-skill. A separate linear program will evaluate each pair of skills (Low Observable and Sheet Metal, General Mechanic and Electrician, Avionics and Fuels Technicians).

The objective function is a function of the decision variables that we want to maximize or minimize. In our linear program, our objective function is to maximize the function of our weights (or objective function coefficients) and our decision variables. Our weights will be represented with the symbols c_1, c_2,…, c_n. The weights exist to ensure our linear program prioritizes multi-skilled technicians over single-skilled, so that we can find the maximum number of multi-skilled technicians given the policy and constraints.

Finally, the constraints need to be defined to accomplish the linear program. Constraints are the limitations or restrictions that apply when making decisions within our mathematical model. These constraints will be represented as a function of the decision variables. The value of the function will either be less than or equal to, equal to, or greater than or equal to, a specified value represented by the symbols b_1, b_2, …, b_n. The constraints function may be referred to as the left-hand-side (LHS) and the specified value b may be referred to as the right-hand-side (RHS), due to their location in a typical mathematical model formulation.

In a generic form, the linear program formulation will look like Equations 1 – 9. There are some variables identified that will change (i.e. a_{11}, a_{22}, b_1, b_2, etc). These variables will be defined below.

$$
\begin{array}{llllllllllllll}
\text{MAX:} & 1 & X_1 & + & 1 & X_2 & + & 1000 & X_3 & + & 1000 & X_4 & & & (1) \\
\text{Subject to:} & a_{11} & X_1 & + & 0 & X_2 & + & a_{13} & X_3 & + & a_{14} & X_4 & = & b_1 & (2) \\
 & 0 & X_1 & + & a_{22} & X_2 & + & a_{23} & X_3 & + & a_{24} & X_4 & = & b_2 & (3) \\
 & 1 & X_1 & & & & + & 1 & X_3 & & & & \leq & b_3 & (4) \\
 & & & & 1 & X_2 & & & & + & 1 & X_4 & \leq & b_4 & (5) \\
 & 1 & X_1 & & & & & & & & & & \geq & 0 & (6) \\
 & & & & 1 & X_2 & & & & & & & \geq & 0 & (7) \\
 & & & & & & & 1 & X_3 & & & & \geq & 0 & (8) \\
 & & & & & & & & & & 1 & X_4 & \geq & 0 & (9)
\end{array}
$$

Symbols X_1 – X_4 represent the decision variables. X_1 and X_2 will be an employee who is only trained in one of the skills of the investigated pair. For example, X_1 might be our Low Observables technician, and X_2 might be Sheet Metals technician (or Avionics and Fuels, or General Mechanic and Electrician). X_3 and X_4 represent multi-skilled technicians, with different specialties. X_3 will be a multi-skilled technician who specializes in the X_1 skill, and X_4 will be a multi-skilled technician who specializes in the X_2 skill. For example, X_3 might be a multi-skilled technician who specializes in Low Observables and performs that skill 90 percent of the time, and then 10 percent of the time he/she performs Sheet Metals skill. X_4 might be a multi-skilled technician who specializes in Sheet Metals skill and performs that skill 90 percent of the time, and then 10 percent of the time performs Low Observables skill.

The coefficients in front of the decision variables in equation 1 ($c_1 – c_4$ in linear programming notation) represent the weights. The research wants the mathematical model to prioritize the multi-skilled technicians in order to determine the maximum number of multi-skilled technicians the workload could support. For this reason, c_1 and c_2 will have values of 1, and c_3 and c_4 will have values of 1000. These weights are combined with the decision variables to form our objective function in Equation 1, and the goal is to maximize the sum of the weighted decision variables, subject to several constraints.

Equations 2-9 represent the constraints. The constraints are a function of the decision variables as well as numeric coefficients (in linear programming notation, symbol a_{ij}, where i is the *i*th constraint and j is the *j*th decision variable). Equations 2 and 3 are to ensure that the number of employees employed (X_1-X_4) can meet the annual workload. Equation 2 ensures the annual workload (in hours) for the skill represented by decision variable X_1 is met, and equation 3 ensures the annual workload (in hours) for the skill represented by decision variable X_2 is met. We specify the annual workload on the right-hand-side of the constraint, values b_1 and b_2. The coefficients for these constraints, a_{ij}, are the annual output per employee. The annual output per employee is dependent on a measure known as Output per Man Day (OPMD). OPMD multiplied by the number of workdays in a year (225) will give the annual output. The F-22 maintenance depot has a target or goal of 5.6 OPMD (or 5.6 hours output per day per employee), but may experience OMPDs as low as 4.0 or lower. For this reason, we will examine constraints that use 4.0 OMPD (900 hours annual output) as well as constraints that use 5.6 OPMD (1260 hours annual output). Coefficient a_{11} is the annual output one employee of X_1

contributes to the X_1 skill. Coefficient a_{21} is the annual output one employee of X_2 contributes to the X_1 skill (0 hours, he is trained 100% in the X_2 skill). Coefficient a_{31} and a_{41} are the annual output X_3 and X_4 contribute to the X_1 skill. These coefficients will be varied as we examine different levels of specialization (10 percent, 25 percent, and 50 percent) with the X_3 and X_4 employees. For example, if we examine a 10 percent specialization, the X_3 employee will perform skill X_1 90 percent of the time and X_2 10 percent of the time. The X_4 employee will perform skill X_1 10 percent of the time and X_2 90 percent of the time.

There will be similar coefficients as part of equation 3. These coefficients will be the annual output (in hours) that employees $X_1 - X_4$ contribute to skill X_2. X_1 contributes zero hours to X_2, X_2 contributes 100 percent of the annual output to skill X_2, and X_3 and X_4 contribute their annual output based on the specialization percentage. The values for these constraint coefficients can be found in Table 2, and their right hand side values can be found in Table 3 and Table 4.

Table 2: LP Constraint Coefficient Values

	4.0 OPMD			5.6 OPMD		
	10%	25%	50%	10%	25%	50%
a_{11}	900	900	900	1260	1260	1260
a_{13}	810	675	450	1134	945	630
a_{14}	90	225	450	126	315	630
a_{22}	900	900	900	1260	1260	1260
a_{23}	90	225	450	126	315	630
a_{24}	810	675	450	1134	945	630

Table 3: RHS b_1 Values

	2013 State			"Future State"								
	AP	AG	ATAF	AP			AG			ATAF		
				LB	Avg	UB	LB	Avg	UB	LB	Avg	UB
b_1	108340.2	14188.6	8276.3	156247.6	202536.3	241822.8	23190.5	28060.3	32768.3	10485.2	12496.5	15370.2

Table 4: RHS b_2 Values

	2013 State			"Future State"								
	AS	AR	ACAD	AS			AR			ACAD		
				LB	Avg	UB	LB	Avg	UB	LB	Avg	UB
b_2	41145.1	9431.5	3040.7	61786.7	79955.2	107714.8	11341.3	14319.8	17515.6	4164.8	4973.4	5647.0

Equations 4-5 ensure that staffing decisions are bounded by the number of employees Ogden ALC has. If the linear program cannot reach an optimal solution (there are not enough employees to complete the annual workload), then the constraint is removed and re-calculated. A comment will be included that the linear program could not be solved, and therefore additional employees are required. The value for the right hand side values of equations 4 and 5 can be found in Table 5 and Table 6.

Table 5: RHS b_3 Values

	2013 State			"Future State"		
	AP	AG	ATAF	AP	AG	ATAF
b_3	96	21	9	121	57	13

Table 6: RHS b_4 Values

	2013 State			"Future State"		
	AS	AR	ACAD	AS	AR	ACAD
b_4	54	12	6	51	6	16

Equations 6-9 ensure that the values of X_1 – X_4 are non-negative, since we cannot have a negative number of employees.

A linear program will be written using 2013 data and calculated future state data, each skill pairing (3 skill pairings), both an OPMD of 4.0 and 5.6, as well as different specialization policies (10 percent, 25 percent, 50 percent). There is several software capable of solving linear programming models. The software used is Microsoft Excel, which comes pre-installed with a solver utility that can be enabled in the add-ins. The output of the linear program will be the exact number of employees (to a fraction of an employee) needed to meet a specified annual workload, while ensuring that a minimal amount of time is spent in a skill. The outputs are summarized in Chapter 4. Full outputs can be found in Appendix A.

Research Question #2

Once you know how many people you need, you need to know how to schedule them. It is an easy decision when you have a single skill, if you are a sheet metal technician, you are assigned a sheet metal job. If you are a low observables painter and a sheet metal technician, the decision gets a little more complicated. It also has big implications on how much time a set of jobs will take to accomplish. The researcher will apply scheduling theory to identify an easy rule of thumb, or heuristic, that a supervisor can employ to get the best results out of the employees. The heuristic may not be optimal in every situation. Due to the complexity of the problem, optimality cannot be guaranteed with a simple heuristic. It would take a computer testing every possible combination to reach the solution. However, a heuristic can be good enough, as demonstrated below, and it is easy to implement.

The fuels/avionics skill pairings will be used to explore scheduling rules. However, the heuristic will benefit all skill pairings. To setup the environment to test scheduling rules, a week's worth of operation data (4-8 March 2013) is used for these skills. Additionally, the staffing decisions from Table 7 are used to decide on the workforce based on an OPMD of 5.6 and a 50% minimum time policy (five fuels technicians and five multi-skilled fuels/avionics technicians).

Scheduling theory uses the following notation, referred to as a triplet, to describe the environment: $\alpha \mid \beta \mid \gamma$. The α describes the machine environment, β describes the constraints, and γ describes the objective. For the fuels/avionics environment, the triplet will be $P10 \mid Mj \mid C_{Max}$. P10 means there are 10 identical machines in parallel (the employees). The machines are not identical in the sense of the jobs they can process, but they are identical in the time it takes to process a job. The constraint 'Mj' indicates that some jobs can only be processed by a specific machine. For example, an avionics job must be processed by the multi-skilled fuels/avionics technician; it cannot be processed by the fuels technician. A fuels job can be processed by either the fuels technician or the multi-skilled fuels/avionics technician. The objective 'C_{max}' is the completion time of the last job, and we are trying to minimize that, resulting in the shortest flow time. In addition to the previous notation, p_j is used to indicate the processing time of job 'j'. For example, if job 3 takes 4 units of time to complete, then $p_3 = 4$.

Common scheduling heuristics are applied and examine for the effect they have on makespan (when all jobs have been completed). The shortest processing time first (SPT) rule, the longest processing time first (LPT) rule, and the least flexible job (LFJ) rule are all examined, and the results are compared to a random assignment of jobs to machines. The researcher expects that a rule exists that will provide supervisors with an easy and effective way to assign work to employees that is superior to randomly assigning jobs. The lower bound, or optimal solution, for this problem is 39.67 hours to complete the workload for 4-8 March 2013. This is obtained by dividing the total hours (396.7 hours based on PDMSS data), and the number of machines (10 employees). It may be impossible to achieve the optimal solution based on the mix of jobs and machines, but it does give a target.

The shortest processing time (SPT) first rule assigns the shortest processing jobs first to available machines. Arrange the jobs by processing time such that $p_1 \leq p_2 \leq \ldots \leq p_n$. At time 0, all machines should be free. For the jobs at the F-22 depot, some jobs are longer than a shifts worth of work. In these cases, the jobs are broken into equal parts so that they were below the expected shift output (OPMD). These job parts could be assigned to two different machines at the same time, representing two employees working together, or assigned to one machine back to back, representing a job being picked up by the next shift. Assign p_1 to the first available machine, p_2 to second available machine, etc, until all machines are busy. Then, the first machine that becomes available starts processing the lowest processing time job that hasn't been started yet, and this is repeated until all jobs have been processed. This rule will be modified for the avionics/fuels problem, because the environment has machine eligibility restrictions. Avionics jobs must be processed by the multi-skilled technician, because multi-skilled technicians are the only ones who will be qualified for avionics in this example. Fuels jobs can be processed by either the fuels technicians or the multi-skilled technicians. If, at the sixth hour, a fuels technician becomes available and the lowest processing time job is an avionics job, then skip that job and assign the lowest fuel job. When the next multi-skilled technician becomes available next, process the avionics job.

The longest processing time (LPT) first rule assigns the longest processing jobs first to available machines. Arrange the jobs by processing time such that $p_1 \geq p_2 \geq \ldots \geq p_n$. At time 0, all machines should be free. Assign p_1 to the first available machine, p_2 to second available machine, etc, until all machines are busy. Then, the first machine that becomes available starts processing the longest processing time job that hasn't been started yet, and this is repeated until all jobs have been processed. This rule will be modified similar to our SPT rule to account for machine eligibility restrictions.

The least flexible job (LFJ) rule is typically applied in problems that have processing time equal to 1 for all jobs. Since the jobs at Ogden ALC have varying processing times, both SPT and LPT will be applied with LFJ and the results compared. When a machine becomes available, the least flexible job is assigned to that machine. Remember that the least flexible job is the job that can be processed by the fewest number of machines. In this case, we could assign a fuels job or an avionics job to the machine. The fuels job can be processed by all ten machines (five fuels technicians can process a fuels job, plus five multi-skilled technicians can process a fuels job). The avionics job can only be processed by five machines (our five fuels technicians cannot process an avionics job, but five multi-skilled technicians can process an avionics job). Since the avionics job can only be processed by five machines (versus the ten machines that a fuels job can be processed by), the avionics job is the least flexible job and should always be processed before a fuels job if possible. If a fuels technician becomes available, the fuels technician cannot process the avionics, they must process a fuels job. However, if a multi-skilled technician becomes available, the multi-skilled technician should process the least flexible job, which in this case is the avionics job (5 machines versus 10 machines).

These heuristics will be applied to the scheduling problem, and the results will appear in Chapter IV, Results and Analysis.

IV. Results and Analysis

Chapter Overview

This chapter is separated into two different sections. The first section will provide the results to the first research question, "How many employees can you multi-skill and maintain a minimum level of proficiency?" and the second section will provide the results to the scheduling problem. The first section is further divided into two sub-sections: One focusing on the state of the depot in 2013, and the other focusing on an estimated "Future State".

Research Question #1

The researcher sought to answer "How many employees can you multi-skill and maintain a minimum level of proficiency?" Minimum annual time policies were applied to ensure opportunities exist to remain active and proficient in the skills, and staffing decisions were solved using linear programming. The staffing decision answers are contained in Table 7 through Table 18. The tables contain the exact number of employees to maintain in each skill to meet the annual workload, given specialization policies. Note: it is the exact number of employees in each skill, working 225 days a year at OPMD rates. It will be important to adjust based on leave/sick rates, and fluctuations in OPMD.

2013 State.

The multi-skilling staffing needs for the depot based on 2013 data were calculated to mirror Capt Sheppard's research.

Table 7: 2013, 4.0 AP/AS Staffing Decisions

OPMD 4.0					
	AP	AS	AP/AS	AS/AP	Total Personnel
10% Policy	LP could not solve with current staffing numbers. There is a shortage of 14485.3 AP/AS hours, or approximately 16.0 employees.				166.0 AP and AS Technicians
25% Policy	LP could not solve with current staffing numbers. There is a shortage of 14485.3 AP/AS hours, or approximately 16.0 employees.				166.0 AP and AS Technicians
50% Policy	LP could not solve with current staffing numbers. There is a shortage of 14485.3 AP/AS hours, or approximately 16.0 employees.				166.0 AP and AS Technicians

Table 8: 2013, 4.0 AG/AR Staffing Decisions

OPMD 4.0					
	AG	AR	AG/AR	AR/AG	Total Personnel
10% Policy	0.0	0	16.4	9.8	26.2 AG and AR Technicians
25% Policy	0.0	0	18.4	7.8	26.2 AG and AR Technicians
50% Policy	5.3	0	9.0	12.0	26.2 AG and AR Technicians

Table 9: 2013, 4.0 ATAF/ACAD Staffing Decisions

OPMD 4.0					
	ATAF	ACAD	ATAF/ ACAD	ACAD/ ATAF	Total Personnel
10% Policy	7.4	0	1.6	3.6	12.5 ATAF and ACAD Technicians
25% Policy	6.2	0	2.8	3.6	12.5 ATAF and ACAD Technicians
50% Policy	5.8	0	0.8	6.0	12.5 ATAF and ACAD Technicians

Table 7 through Table 9 shows the exact number of employees needed to meet the 2013 annual workload, based on a 4.0 OPMD. The four columns for each skill pairing is broken up such that the first two column represents employees who spends 100 percent of their time in their respective skill, and the third and fourth column represents multi-skilled employees who specialize and spend varying percentages of time in both skills. For example, examining the AP and AS skill pairing and a 10% policy, the third column (AP/AS) is a multi-skilled employee who spends 90 percent of his time performing AP skills and 10 percent of his time performing AS skills. The fourth column (AS/AP) is a multi-skilled employee who spends 90 percent of his time performing AS skills and 10 percent of his time performing AP skills.

Table 10: 2013, 5.6 AP/AS Staffing Decisions

OPMD 5.6					
	AP	AS	AP/AS	AS/AP	Total Personnel
10% Policy	0.0	0	92.7	26.0	118.64 AP and AS Technicians
25% Policy	33.3	0	62.7	22.6	118.64 AP and AS Technicians
50% Policy	53.3	0	11.3	54.0	118.64 AP and AS Technicians

Table 11: 2013, 5.6 AG/AR Staffing Decisions

OPMD 5.6					
	AG	AR	AG/AR	AR/AG	Total Personnel
10% Policy	0.0	0	11.7	7.0	18.75 AG and AR Technicians
25% Policy	0.0	0	13.1	5.6	18.75 AG and AR Technicians
50% Policy	3.8	0	3.0	12.0	18.75 AG and AR Technicians

Table 12: 2013, 5.6 ATAF/ACAD Staffing Decisions

OPMD 5.6					
	ATAF	ACAD	ATAF/ ACAD	ACAD/ ATAF	Total Personnel
10% Policy	0.0	0	7.1	1.9	8.98 ATAF and ACAD Technicians
25% Policy	0.0	0	8.6	0.3	8.98 ATAF and ACAD Technicians
50% Policy	4.2	0	0.0	4.8	8.98 ATAF and ACAD Technicians

Table 10 through Table 12 shows the exact number of employees needed to meet the 2013 annual workload, based on a 5.6 OPMD.

"Future State".

The "Future State" nearly doubled the capacity of Ogden ALC (from maximum of 7 work in progress to 13). This "Future State" represents the maintenance currently conducted at a facility in Palmdale California shifting to Ogden ALC. Staffing decisions were calculated based on 4.0 OPMD and 5.6 OPMD.

Table 13: "Future", 4.0 AP/AS Staffing Decisions

OPMD 4.0						
		AP	AS	AP/AS	AS/AP	Total Personnel
10% Policy	L.B.	LP could not solve with current staffing numbers. There is a shortage of 63234.3 AP/AS hours, or approximately 70.2 employees.				242.2 AP and AS Technicians
	Average	LP could not solve with current staffing numbers. There is a shortage of 127691.5 AP/AS hours, or approximately 141.8 employees.				313.9 AP and AS Technicians
	U.B.	LP could not solve with current staffing numbers. There is a shortage of 194737.6 AP/AS hours, or approximately 216.3 employees				388.4 AP and AS Technicians
25% Policy	L.B.	LP could not solve with current staffing numbers. There is a shortage of 63234.3 AP/AS hours, or approximately 70.2 employees.				242.2 AP and AS Technicians

	Average	LP could not solve with current staffing numbers. There is a shortage of 127691.5 AP/AS hours, or approximately 141.8 employees.	313.9 AP and AS Technicians
	U.B.	LP could not solve with current staffing numbers. There is a shortage of 194737.6 AP/AS hours, or approximately 216.3 employees	388.4 AP and AS Technicians
50% Policy	L.B.	LP could not solve with current staffing numbers. There is a shortage of 63234.3 AP/AS hours, or approximately 70.2 employees.	242.2 AP and AS Technicians
	Average	LP could not solve with current staffing numbers. There is a shortage of 127691.5 AP/AS hours, or approximately 141.8 employees.	313.9 AP and AS Technicians
	U.B.	LP could not solve with current staffing numbers. There is a shortage of 194737.69AP/AS hours, or approximately 216.3 employees	388.4 AP and AS Technicians

Table 14: "Future", 4.0 AG/AR Staffing Decisions

OPMD 4.0						
		AG	AR	AG/AR	AR/AG	Total Personnel
10% Policy	L.B.	LP could not solve with current staffing numbers because of 10% policy, but current staffing can meet the workload (See 25% policy and 50% policy).				38.4 AG and AR Technicians
	Average	LP could not solve with current staffing numbers because of 10% policy, but current staffing can meet the workload (See 25% policy and 50% policy).				47.1 AG and AR Technicians
	U.B.	LP could not solve with current staffing numbers because of 10% policy, but current staffing can meet the workload (See 50% policy).				55.8 AG and AR Technicians
25% Policy	L.B.	0.0	0.037	32.4	6.0	38.4 AG and AR Technicians
	Average	0.0	4.555	41.1	1.4	47.1 AG and AR Technicians
	U.B.	LP could not solve with current staffing numbers because of 10% policy, but current staffing can meet the workload (See 50% policy).				55.8 AG and AR Technicians
50% Policy	L.B.	13.2	0	19.2	6.0	38.4 AG and AR Technicians

	Average	15.3	0	25.8	6.0	47.1 AG and AR Technicians
	U.B.	16.9	0	32.9	6.0	55.8 AG and AR Technicians

Table 15: "Future", 4.0 ATAF/ACAD Staffing Decisions

OPMD 4.0						
		ATAF	ACAD	ATAF/ ACAD	ACAD/ ATAF	Total Personnel
10% Policy	L.B.	0.0	0	12.5	3.7	16.28 ATAF and ACAD Technicians
	Average	LP could not solve with current staffing numbers because of 10% policy, but current staffing can meet the workload (See 25% policy and 50% policy).				19.41 ATAF and ACAD Technicians
	U.B.	LP could not solve with current staffing numbers because of 10% policy, but current staffing can meet the workload (See 50% policy).				23.35 ATAF and ACAD Technicians
25% Policy	L.B.	4.3	0	8.7	3.3	16.28 ATAF and ACAD Technicians
	Average	10.1	0	2.9	6.4	19.41 ATAF and ACAD Technicians
	U.B.	LP could not solve with current staffing numbers because of 10% policy, but current staffing can meet the workload (See 50% policy).				23.35 ATAF and ACAD Technicians
50% Policy	L.B.	7.0	0	0.0	9.3	16.28 ATAF and ACAD Technicians
	Average	8.4	0	0.0	11.1	19.41 ATAF and ACAD Technicians
	U.B.	10.8	0	0.0	12.5	23.35 ATAF and ACAD Technicians

Table 13 through Table 15 shows the exact number of employees needed to meet the estimated "Future State" annual workload, based on a 4.0 OPMD.

Table 16: "Future", 5.6 AP/AS Staffing Decisions

OPMD 5.6						
		AP	AS	AP/AS	AS/AP	Total Personnel
10%	L.B.	LP could not solve with current staffing				173.0 AP and AS

Policy		numbers. There is a shortage of 1314.3 AP/AS hours, or approximately 1.0 employees.	Technicians
	Average	LP could not solve with current staffing numbers. There is a shortage of 65771.5 AP/AS hours, or approximately 52.1 employees.	224.2 AP and AS Technicians
	U.B.	LP could not solve with current staffing numbers. There is a shortage of 132817.6 AP/AS hours, or approximately 105.4 employees.	277.4 AP and AS Technicians
25% Policy	L.B.	LP could not solve with current staffing numbers. There is a shortage of 1314.3 AP/AS hours, or approximately 1.0 employees.	173.0 AP and AS Technicians
	Average	LP could not solve with current staffing numbers. There is a shortage of 65771.5 AP/AS hours, or approximately 52.1 employees.	224.2 AP and AS Technicians
	U.B.	LP could not solve with current staffing numbers. There is a shortage of 132817.6 AP/AS hours, or approximately 105.4 employees.	277.4 AP and AS Technicians
50% Policy	L.B.	LP could not solve with current staffing numbers. There is a shortage of 1314.3 AP/AS hours, or approximately 1.0 employees.	173.0 AP and AS Technicians
	Average	LP could not solve with current staffing numbers. There is a shortage of 65771.5 AP/AS hours, or approximately 52.1 employees.	224.2 AP and AS Technicians
	U.B.	LP could not solve with current staffing numbers. There is a shortage of 132817.6 AP/AS hours, or approximately 105.4 employees.	277.4 AP and AS Technicians

Table 17: “Future”, 5.6 AG/AR Staffing Decisions

OPMD 5.6						
		AG	AR	AG/AR	AR/AG	Total Personnel
10% Policy	L.B.	LP could not solve with current staffing numbers because of 10% policy, but current staffing can meet the workload (See 25% policy and 50% policy).				27.4 AG and AR Technicians

	Average	LP could not solve with current staffing numbers because of 10% policy, but current staffing can meet the workload (See 25% policy and 50% policy).				33.6 AG and AR Technicians
	U.B.	LP could not solve with current staffing numbers because of 10% policy, but current staffing can meet the workload (See 25% policy and 50% policy).				39.9 AG and AR Technicians
25% Policy	L.B.	0.0	0	23.1	4.3	27.41 AG and AR Technicians
	Average	0.0	0	27.7	5.9	33.6 AG and AR Technicians
	U.B.	0.0	3.6	33.9	2.3	39.9 AG and AR Technicians
50% Policy	L.B.	9.4	0	12.0	6.0	27.4 AG and AR Technicians
	Average	10.9	0	16.7	6.0	33.6 AG and AR Technicians
	U.B.	12.1	0	21.8	6.0	39.9 AG and AR Technicians

Table 18: "Future", 5.6 ATAF/ACAD Staffing Decisions

OPMD 5.6						
		ATAF	ACAD	ATAF/ ACAD	ACAD/ ATAF	Total Personnel
10% Policy	L.B.	0.0	0	8.9	2.7	11.6 ATAF and ACAD Technicians
	Average	0.0	0	10.7	3.2	13.8 ATAF and ACAD Technicians
	U.B.	1.3	0	11.7	3.7	16.6 ATAF and ACAD Technicians
25% Policy	L.B.	0.0	0	10.8	0.8	11.6 ATAF and ACAD Technicians
	Average	0.0	0	12.9	1.0	13.8 ATAF and ACAD Technicians
	U.B.	6.1	0	6.9	3.7	16.6 ATAF and ACAD Technicians
50% Policy	L.B.	5.0	0	0.0	6.6	11.6 ATAF and ACAD Technicians
	Average	6.0	0	0.0	7.9	13.8 ATAF and ACAD Technicians
	U.B.	7.7	0	0.0	9.0	16.6 ATAF and ACAD Technicians

Table 16 through Table 18 shows the exact number of employees needed to meet the estimated "Future State" annual workload, based on a 5.6 OPMD.

Table 19: Summary, "Future State" Average Workload

	AP/AS	AG/AR	ATAF/ACAD	Total
4.0 OPMD Avg Workload	313.9 AP/AS Technicians	47.1 AG/AR Technicians	19.4 ATAF/ ACAD Technicians	380.4 Technicians
5.6 OPMD Avg Workload	224.2 AP/AS Technicians	33.6 AG/AR Technicians	13.8 ATAF/ ACAD Technicians	271.7 Technicians

Table 19 contains a summary of "Future State" estimates of workforce to accomplish an average workload. Sheppard (2014) estimated a similar size workforce in his thesis. Sheppard (2014) estimated that the workforce to meet the future state and meet flow day targets would be between 348-396 technicians (Sheppard, 2014:102). The slight differences are expected due to the different methodologies and systems used to reach the conclusions, but the similarities should serve as a validation of both works.

Research Question #2

After the number of employees that can be multi-skilled is determined, the researcher looked at how to schedule them. A week's worth of fuels and avionics work was examined (396.7 hours in our case), and sought to find an easy and effective way to schedule the employees with a goal to minimize the makespan. Common scheduling heuristics were applied to the problem, and the makespans can be found in Table 20. Visual representations of the scheduling heuristics can be found in Figure 2 through Figure 6. Fuels jobs, which are processed by either the ATAF (fuels) technician or the multi-skilled ATAF/ACAD (fuels/avionics) technician, are blue in color in the visual representation. Avionics jobs, which are processed by only the multi-skilled ATAF/ACAD (fuels/avionics) technician, are yellow in color in the visual representation.

Table 20: Scheduling Results

	Random	LPT	SPT	LFJ-LPT	LFJ-SPT
Makespan	47 hours	40.7 hours	57.9 hours	40.7 hours	42.4 hours

The best rule applied in the example was Longest Processing Time First (LPT) Rule, and Least Flexible Job (LFJ) with Longest Processing Time (LPT), both processing the weeks' worth of work in 40.7 hours. The lower bound on this problem is 39.67 hours, but it is unachievable due to more hours in avionics than fuels in our example, therefore impossible to assign 39.67 hours of work to all ten employees. In this instance, LPT and LFJ-LPT are only 2.5 percent over the optimal solution (40.7 divided by 39.67). Additionally, given this example and the finite amount of work, technicians achieved on average a 97.4 percent utilization rate.

The next best rule applied in this case was Least Flexible Job (LFJ) with Shortest Processing time (SPT), processing the weeks' worth of work in 42.4 hours. LFJ-SPT was 6.8 percent over the optimal solution, with technicians achieving on average a 93.5 percent utilization rate. Randomly assigning jobs to technicians completed the weeks' worth of work in 47 hours. This came in 18.4 percent over the optimal solution, with technicians achieving on average 84.3 percent utilization rate. Finally, Shortest Processing Time (SPT) first completed the weeks' work in 57.9 hours. SPT was 45.9

percent over the optimal solution, with technicians achieving on average 68.4 percent utilization.

It is important to note how the different policies compare. There is a big difference between the best policy and the worst policy, and this demonstrates how a lack of thought in assignment of work can result in a later completion time, possibly resulting in overtime. The Least Flexible Job (LFJ) with Longest Processing time (LPT) does not require a lot of thought but can make significant improvements over other policies.

V. Conclusions and Recommendations

Answers to Research Questions

Research Question 1: How many employees can be multi-skilled and maintain a minimum level of proficiency?

Table 7 through Table 18 contains the exact number of employees to meet the annual workload based on OPMD and state of the depot (2013 state or “Future State”). As a user of the table, first select the OPMD value that is currently being achieved. Then, decide on how specialized or generalized you want your multi-skilled technicians to be. By employing a 10 percent specialization policy, there is opportunity to maintain some of those expert skills the technicians have, but gives them little opportunity to perform the secondary skill. If a 50 percent specialization policy is employed, employees get equal opportunity in both skills to perform the skills, but some of those expert skills may be lost.

The numbers of employees the table reports can include fractional employees. Round up in this case to ensure the annual workload is met, but also consider increasing the number of employees to account for leave/sickness/attrition/etc. Keep in mind that increasing the number of employees will decrease the opportunity to perform their skills.

The specialization policy ensures that there is opportunity for employees to practice both skills. However, that is just one of many techniques that can be applied to mitigate against proficiency loss and increase skill retention. There are many techniques can be applied during the training phase that will help with skill retention, as found in

Chapter 2. These techniques include dyadic training methods, overlearning, feedback, peer support, and managerial support. If dyadic training methods were applied, it would be useful to take advantage of that efficiency by doubling the training of each employee, as overlearning has been shown to increase the skills transfer and skills retention.

After conducting the research, it is the researcher's opinion that targeting multi-skilling towards a 25 percent specialization policy and a 5.6 OPMD figure would be a great place to start. There is no way to determine the amount of skill loss that Ogden ALC will experience after multi-skilling short of experimenting and measuring at the site. However, the literature provides that skill loss is a function of the retention interval (the length the skill goes unpracticed), so any attempts to minimize the retention interval will help mitigate skill loss. At 10 percent specialization, the technician will go (on average) nine weeks without practicing the skill for every one week of use. At 25 percent specialization, the technician will go three weeks without practice for every one week of use. Additionally, multi-skilling should increase technician utilization rates resulting in a higher OPMD than currently being experienced. Without multi-skilling, the unit might be experiencing lower OPMDs that approach 4.0, but with multi-skilling and the increased utilization rates, a higher OPMD should be achievable. After operating at the chosen specialization policy, it is possible to adjust to a more specialized or more generalized workforce based on observations from the policy's implementation, or increase/decrease personnel numbers based on OPMDs being experienced.

Research Question 2: Once multi-skilled, is there any technique to scheduling the multi-skilled workforce?

There are multiple techniques to schedule the multi-skilled workforce. The research recommends using the Least Flexible Job (LFJ) with Longest Processing Time First (LPT) rule. It is an easy rule to apply. A week's worth of work was examined and the rule was applied, but the rule could be applied day to day, or gate to gate. The supervisor responsible for handing out work assignments just needs to assign each worker the least flexible job (if a job can only be processed by three of ten employees because it is an avionics job, it is important to assign it to the avionics technician) and the longest processing time job first.

This scheduling rule and the specialization policy will not ensure that employees are spending time outside of their specialties. The specialization policy only ensures that an opportunity exists to spend time outside their specialty. It will take careful monitoring by employees and supervisors to ensure employees are practicing all skills. Managing the proficiency of employees would be best left to a computer system if possible. Employees are currently logging their time worked in the GO97 system. It may make sense to increase the capabilities of the GO97 through an update that allows for proficiency tracking.

Limitations

1) When attempting to maximize the number of multi-skilled personnel, the model has a tendency to favor more of the alternative multi-skilled technicians as opposed to the primary multi-skilled technicians.

2) The model assumes that when a 5.6 OPMD is applied, that both the single-skilled and multi-skilled personnel are operating at 5.6 OPMD. One of the benefits of

multi-skilling is that there will be better utilization rates, which lends to the conclusion that multi-skilled personnel will operate at a higher OPMD than single-skilled personnel. This limitation is mitigated in the cases where single-skilled personnel are not chosen at all, since the model favors multi-skilled personnel. If the model assigns single-skilled personnel, it may be necessary to increase single-skilled numbers to offset for any differences between the actual and estimated OPMD.

3) Behavioral concerns were not considered. Skill pairings determined by Sheppard (2014) were used in this research, but behavior may reduce the effectiveness or output if a pairing is viewed negatively. If an employee is unhappy about being paired with a certain skill, their expected contribution towards that skill may be much lower as a form of resistance. Leaders should be cognizant of this effect and interview potential multi-skilled technicians to recruit only those who view the pairing positively.

Future Research

This research concludes with several opportunities for future research.

1) A measured study of the actual skills retention and skills loss experienced after multiskilling at Ogden ALC. There is a plethora of literature that supports various techniques in mitigating skill loss, but each environment is unique and it would be useful to examine the effects of these techniques at Ogden ALC.
2) A study exploring the motivation of the different career fields to merge. Skill pairings were determined based on utilization, man-hour requirements, and size, but they were not paired based on skill similarities. Fuels and Avionics are

extremely different career fields. It would be useful to evaluate the likelihood of a skill pairing success.

Appendix 1: Linear Program Outputs

Table 21 through Table 90 contain the outputs of the linear program, varied depending on the state of the depot, OPMD value, specialization policy, and the skill pairing. The inputs to the linear program are indicated at the top of each table, and the linear program follows. The objective function value (the green box) is not important. Our linear program sought to maximize this value based on our arbitrary weights that ensured multi-skilled technicians were given priority. The decision variables (the yellow boxes) are important. They are the number of employees needed given the inputs provided at the top of each table.

2013 State

Table 21: 2013, 4.0, 10%, AS/AP

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum AP Policy	10%

Inputs	
AP Total Hours	108340.20
AS Total Hours	41145.10

	AP	AS	AP/AS	AS/AP	
Decision Variables	0.0	0	129.7	36.4	
Weighted Objective	1	1	1000	1000	166094.78

Note: LP could not be solved using 2013 staffing numbers. The table represents the solution if additional employees could be hired.

Table 22: 2013, 4.0, 25%, AS/AP

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum AP Policy	25%

Inputs	
AP Total Hours	108340.20
AS Total Hours	41145.10

	AP	AS	AP/AS	AS/AP	
Decision Variables	0.0	0	157.7	8.4	
Weighted Objective	1	1	1000	1000	166094.78

Note: LP could not be solved using 2013 staffing numbers. The table represents the solution if additional employees could be hired.

Table 23: 2013, 5.6, 50%, AS/AP

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum AP Policy	50%

Inputs	
AP Total Hours	108340.20
AS Total Hours	41145.10

AP	AS	AP/AS	AS/AP

Decision Variables	74.7	0	0.0	91.4	
Weighted Objective	1	1	1000	1000	91508.22

Note: LP could not be solved using 2013 staffing numbers. The table represents the solution if additional employees could be hired.

Table 24: 2013, 5.6, 10%, AS/AP

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum AP Policy	10%

Inputs	
AP Total Hours	108340.20
AS Total Hours	41145.10
AP Total Emp	96
AS Total Emp	54

	AP	AS	AP/AS	AS/AP	
Decision Variables	0.0	0	92.7	26.0	
Weighted Objective	1	1	1000	1000	118639.13

Table 25: 2013, 5.6, 25%, AS/AP

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum AP Policy	25%

Inputs	
AP Total Hours	108340.20
AS Total Hours	41145.10
AP Total Emp	96
AS Total Emp	54

	AP	AS	AP/AS	AS/AP	
Decision Variables	33.3	0	62.7	22.6	
Weighted Objective	1	1	1000	1000	85374.41

Table 26: 2013, 4.0, 50%, AS/AP

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum AP Policy	50%

Inputs	
AP Total Hours	108340.20
AS Total Hours	41145.10
AP Total Emp	96
AS Total Emp	54

	AP	AS	AP/AS	AS/AP	
Decision Variables	53.3	0	11.3	54.0	
Weighted Objective	1	1	1000	1000	65363.01

Table 27: 2013, 4.0, 10%, AG/AR

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum AG Policy	10%

Inputs	
AG Total Hours	14188.60
AR Total Hours	9431.50
AG Total Emp	21
ARTotal Emp	12

	AG	AR	AG/AR	AR/AG
Decision Variables	0.0	0	16.4	9.8

Weighted Objective	1	1	1000	1000	26244.56

Table 28: 2013, 4.0, 25%, AG/AR

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum AG Policy	25%

Inputs	
AG Total Hours	14188.60
AR Total Hours	9431.50
AG Total Emp	21
ARTotal Emp	12

	AG	AR	AG/AR	AR/AG	
Decision Variables	0.0	0	18.4	7.8	
Weighted Objective	1	1	1000	1000	26244.56

Table 29: 2013, 4.0, 50%, AG/AR

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum AG Policy	50%

Inputs	
AG Total Hours	14188.60
AR Total Hours	9431.50
AG Total Emp	21
ARTotal Emp	12

	AG	AR	AG/AR	AR/AG	
Decision Variables	5.3	0	9.0	12.0	
Weighted Objective	1	1	1000	1000	20964.17

Table 30: 2013, 5.6, 10%, AG/AR

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum AG Policy	10%

Inputs	
AG Total Hours	14188.60
AR Total Hours	9431.50
AG Total Emp	21
ARTotal Emp	12

	AG	AR	AG/AR	AR/AG	
Decision Variables	0.0	0	11.7	7.0	
Weighted Objective	1	1	1000	1000	18746.11

Table 31: 2013, 5.6, 25%, AG/AR

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum AG Policy	25%

Inputs	
AG Total Hours	14188.60
AR Total Hours	9431.50
AG Total Emp	21
ARTotal Emp	12

	AG	AR	AG/AR	AR/AG	
Decision Variables	0.0	0	13.1	5.6	
Weighted Objective	1	1	1000	1000	18746.11

Table 32: 2013, 5.6, 50%, AG/AR

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum AG Policy	50%

Inputs	
AG Total Hours	14188.60
AR Total Hours	9431.50
AG Total Emp	21
ARTotal Emp	12

	AG	AR	AG/AR	AR/AG	
Decision Variables	3.8	0	3.0	12.0	
Weighted Objective	1	1	1000	1000	14974.41

Table 33: 2013, 4.0, 10%, ACAD/ATAF

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum ATAF Policy	10%

Inputs	
ATAF Total Hours	8276.30
ACAD Total Hours	3040.70
ATAF Total Emp	9
ACAD Total Emp	6

	ATAF	ACAD	ATAF/ACAD	ACAD/ ATAF	
Decision Variables	7.4	0	1.6	3.6	
Weighted Objective	1	1	1000	1000	5197.38

Table 34: 2013, 4.0, 25%, ACAD/ATAF

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum ATAF Policy	25%

Inputs	
ATAF Total Hours	8276.30
ACAD Total Hours	3040.70
ATAF Total Emp	9
ACAD Total Emp	6

	ATAF	ACAD	ATAF/ACAD	ACAD/ ATAF	
Decision Variables	6.2	0	2.8	3.6	
Weighted Objective	1	1	1000	1000	6371.54

Table 35: 2013, 4.0, 50%, ACAD/ATAF

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum ATAF Policy	50%

Inputs	
ATAF Total Hours	8276.30
ACAD Total Hours	3040.70
ATAF Total Emp	9
ACAD Total Emp	6

	ATAF	ACAD	ATAF/ACAD	ACAD/ ATAF	
Decision Variables	5.8	0	0.8	6.0	
Weighted Objective	1	1	1000	1000	6762.93

Table 36: 2013, 5.6, 10%, ACAD/ATAF

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum ATAF Policy	10%

Inputs	
ATAF Total Hours	8276.30
ACAD Total Hours	3040.70
ATAF Total Emp	9
ACAD Total Emp	6

	ATAF	ACAD	ATAF/ACAD	ACAD/ ATAF	
Decision Variables	0.0	0	7.1	1.9	
Weighted Objective	1	1	1000	1000	8981.75

Table 37: 2013, 5.6, 25%, ACAD/ATAF

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum ATAF Policy	25%

Inputs	
ATAF Total Hours	8276.30
ACAD Total Hours	3040.70
ATAF Total Emp	9
ACAD Total Emp	6

	ATAF	ACAD	ATAF/ACAD	ACAD/ ATAF	
Decision Variables	0.0	0	8.6	0.3	
Weighted Objective	1	1	1000	1000	8981.75

Table 38: 2013, 5.6, 50%, ACAD/ATAF

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum ATAF Policy	50%

Inputs	
ATAF Total Hours	8276.30
ACAD Total Hours	3040.70
ATAF Total Emp	9
ACAD Total Emp	6

	ATAF	ACAD	ATAF/ACAD	ACAD/ ATAF	
Decision Variables	4.2	0	0.0	4.8	
Weighted Objective	1	1	1000	1000	4830.66

"Future State"

Table 39: "Future", Lower Bound, 4.0, 10%, AP/AS

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum AP Policy	10%

Inputs	
AP Total Hours	156247.56
AS Total Hours	61786.77
AP Total Emp	121
AS Total Emp	51

	AP	AS	AP/AS	AS/AP	
Lower Bound DVs	0.0	0	186.7	55.5	
Weighted Objective	1	1	1000	1000	242260.37

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 40: "Future", Average, 4.0, 10%, AP/AS

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum AP Policy	10%

Inputs	
AP Total Hours	202536.33
AS Total Hours	79955.25
AP Total Emp	121
AS Total Emp	51

	AP	AS	AP/AS	AS/AP	
Lower Bound DVs	0.0	0	242.1	71.8	
Weighted Objective	1	1	1000	1000	313879.53

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 41: "Future", Upper Bound, 4.0, 10%, AP/AS

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum AP Policy	10%

Inputs	
AP Total Hours	241822.84
AS Total Hours	107714.84
AP Total Emp	121
AS Total Emp	51

	AP	AS	AP/AS	AS/AP	
Lower Bound DVs	0.0	0	287.3	101.1	
Weighted Objective	1	1	1000	1000	388375.21

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 42: "Future", Lower Bound, 4.0, 25%, AP/AS

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum AP Policy	25%

Inputs	
AP Total Hours	156247.56
AS Total Hours	61786.77
AP Total Emp	121
AS Total Emp	51

	AP	AS	AP/AS	AS/AP	
Lower Bound DVs	0.0	0	226.1	16.2	
Weighted Objective	1	1	1000	1000	242260.37

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 43: "Future", Average, 4.0, 25%, AP/AS

Inputs

Inputs

OPMD	4
Work Days	225
Annual Output	900
Minimum AP Policy	25%

AP Total Hours	202536.33
AS Total Hours	79955.25
AP Total Emp	121
AS Total Emp	51

	AP	AS	AP/AS	AS/AP	
Lower Bound DVs	0.0	0	293.1	20.7	
Weighted Objective	1	1	1000	1000	313879.53

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 44: "Future", Upper Bound, 4.0, 25%, AP/AS

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum AP Policy	25%

Inputs	
AP Total Hours	241822.84
AS Total Hours	107714.84
AP Total Emp	121
AS Total Emp	51

	AP	AS	AP/AS	AS/AP	
Lower Bound DVs	0.0	0	343.2	45.2	
Weighted Objective	1	1	1000	1000	388375.21

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 45: "Future", Lower Bound, 4.0, 50%, AP/AS

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum AP Policy	50%

Inputs	
AP Total Hours	156247.56
AS Total Hours	61786.77
AP Total Emp	121
AS Total Emp	51

	AP	AS	AP/AS	AS/AP	
Lower Bound DVs	105.0	0	0.0	137.3	
Weighted Objective	1	1	1000	1000	137408.89

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 46: "Future", Average, 4.0, 50%, AP/AS

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum AP Policy	50%

Inputs	
AP Total Hours	202536.33
AS Total Hours	79955.25
AP Total Emp	121
AS Total Emp	51

	AP	AS	AP/AS	AS/AP
Lower Bound DVs	136.2	0	0.0	177.7

Weighted Objective	1	1	1000	1000	177814.53

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 47: "Future", Upper Bound, 4.0, 50%, AP/AS

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum AP Policy	50%

Inputs	
AP Total Hours	241822.84
AS Total Hours	107714.84
AP Total Emp	121
AS Total Emp	51

	AP	AS	AP/AS	AS/AP	
Lower Bound DVs	149.0	0	0.0	239.4	
Weighted Objective	1	1	1000	1000	239515.33

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 48: "Future", Lower Bound, 5.6, 10%, AP/AS

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260

Inputs	
AP Total Hours	156247.56
AS Total Hours	61786.77
AP Total Emp	121

Minimum AP Policy	10%		AS Total Emp	51

	AP	AS	AP/AS	AS/AP	
Lower Bound DVs	0.0	0	133.4	39.7	
Weighted Objective	1	1	1000	1000	173043.12

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 49: "Future", Average, 5.6, 10%, AP/AS

Inputs			Inputs	
OPMD	5.6		AP Total Hours	202536.33
Work Days	225		AS Total Hours	79955.25
Annual Output	1260		AP Total Emp	121
Minimum AP Policy	10%		AS Total Emp	51

	AP	AS	AP/AS	AS/AP	
Lower Bound DVs	0.0	0	172.9	51.3	
Weighted Objective	1	1	1000	1000	224199.67

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 50: "Future", Upper Bound, 5.6, 10%, AP/AS

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum AP Policy	10%

Inputs	
AP Total Hours	241822.84
AS Total Hours	107714.84
AP Total Emp	121
AS Total Emp	51

	AP	AS	AP/AS	AS/AP	
Lower Bound DVs	0.0	0	205.2	72.2	
Weighted Objective	1	1	1000	1000	277410.86

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 51: "Future", Lower Bound, 5.6, 25%, AP/AS

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum AP Policy	25%

Inputs	
AP Total Hours	156247.56
AS Total Hours	61786.77
AP Total Emp	121
AS Total Emp	51

	AP	AS	AP/AS	AS/AP	
Lower Bound DVs	0.0	0	161.5	11.6	
Weighted Objective	1	1	1000	1000	173043.12

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 52: "Future", Average, 5.6, 25%, AP/AS

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum AP Policy	25%

Inputs	
AP Total Hours	202536.33
AS Total Hours	79955.25
AP Total Emp	121
AS Total Emp	51

	AP	AS	AP/AS	AS/AP	
Lower Bound DVs	0.0	0	209.4	14.8	
Weighted Objective	1	1	1000	1000	224199.67

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 53: "Future", Upper Bound, 5.6, 25%, AP/AS

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum AP Policy	25%

Inputs	
AP Total Hours	241822.84
AS Total Hours	107714.84
AP Total Emp	121
AS Total Emp	51

AP	AS	AP/AS	AS/AP

Lower Bound DVs	0.0	0	245.1	32.3	
Weighted Objective	1	1	1000	1000	277410.86

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 54: "Future", Lower Bound, 5.6, 50%, AP/AS

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum AP Policy	50%

Inputs	
AP Total Hours	156247.56
AS Total Hours	61786.77
AP Total Emp	121
AS Total Emp	51

	AP	AS	AP/AS	AS/AP	
Lower Bound DVs	75.0	0	0.0	98.1	
Weighted Objective	1	1	1000	1000	98149.21

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 55: "Future", Average, 5.6, 50%, AP/AS

Inputs	
OPMD	5.6
Work Days	225

Inputs	
AP Total Hours	202536.33
AS Total Hours	79955.25

Annual Output	1260		AP Total Emp	121
Minimum AP Policy	50%		AS Total Emp	51

	AP	AS	AP/AS	AS/AP	
Lower Bound DVs	97.3	0	0.0	126.9	
Weighted Objective	1	1	1000	1000	127010.38

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 56: "Future", Upper Bound, 5.6, 50%, AP/AS

Inputs			Inputs	
OPMD	5.6		AP Total Hours	241822.84
Work Days	225		AS Total Hours	107714.84
Annual Output	1260		AP Total Emp	121
Minimum AP Policy	50%		AS Total Emp	51

	AP	AS	AP/AS	AS/AP	
Lower Bound DVs	106.4	0	0.0	171.0	
Weighted Objective	1	1	1000	1000	171082.38

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 57: "Future", Lower Bound, 4.0, 10%, AG/AR

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum AG Policy	10%

Inputs	
AG Total Hours	23190.51
AR Total Hours	11341.39
AG Total Emp	57
ARTotal Emp	6

	AG	AR	AG/AR	AR/AG	
Decision Variables	0.0	0	27.4	11.0	
Weighted Objective	1	1	1000	1000	38368.78

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 58: "Future", Average, 4.0, 10%, AG/AR

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum AG Policy	10%

Inputs	
AG Total Hours	28060.36
AR Total Hours	14319.83
AG Total Emp	57
ARTotal Emp	6

	AG	AR	AG/AR	AR/AG	
Decision Variables	0.0	0	33.1	14.0	
Weighted Objective	1	1	1000	1000	47089.10

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 59: "Future", Upper Bound, 4.0, 10%, AG/AR

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum AG Policy	10%

Inputs	
AG Total Hours	32768.36
AR Total Hours	17515.64
AG Total Emp	57
ARTotal Emp	6

	AG	AR	AG/AR	AR/AG	
Decision Variables	0.0	0	38.5	17.3	
Weighted Objective	1	1	1000	1000	55871.11

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 60: "Future", Lower Bound, 4.0, 25%, AG/AR

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum AG Policy	25%

Inputs	
AG Total Hours	23190.51
AR Total Hours	11341.39
AG Total Emp	57
ARTotal Emp	6

	AG	AR	AG/AR	AR/AG	
Decision Variables	0.0	0.037	32.4	6.0	
Weighted Objective	1	1	1000	1000	38331.43

Table 61: "Future", Average, 4.0, 25%, AG/AR

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum AG Policy	25%

Inputs	
AG Total Hours	28060.36
AR Total Hours	14319.83
AG Total Emp	57
ARTotal Emp	6

	AG	AR	AG/AR	AR/AG	
Decision Variables	0.0	4.555	41.1	1.4	
Weighted Objective	1	1	1000	1000	42539.08

Table 62: "Future", Upper Bound, 4.0, 25%, AG/AR

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum AG Policy	25%

Inputs	
AG Total Hours	32768.36
AR Total Hours	17515.64
AG Total Emp	57
ARTotal Emp	6

	AG	AR	AG/AR	AR/AG
Decision Variables	0.0	0	44.9	11.0

Weighted Objective	1	1	1000	1000	55871.11

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 63: "Future", Lower Bound, 4.0, 50%, AG/AR

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum AG Policy	50%

Inputs	
AG Total Hours	23190.51
AR Total Hours	11341.39
AG Total Emp	57
ARTotal Emp	6

	AG	AR	AG/AR	AR/AG	
Decision Variables	13.2	0	19.2	6.0	
Weighted Objective	1	1	1000	1000	25216.25

Table 64: "Future", Average, 4.0, 50%, AG/AR

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum AG Policy	50%

Inputs	
AG Total Hours	28060.36
AR Total Hours	14319.83
AG Total Emp	57
ARTotal Emp	6

AG	AR	AG/AR	AR/AG

Decision Variables	15.3	0	25.8	6.0	
Weighted Objective	1	1	1000	1000	31837.10

Table 65: "Future", Upper Bound, 4.0, 50%, AG/AR

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum AG Policy	50%

Inputs	
AG Total Hours	32768.36
AR Total Hours	17515.64
AG Total Emp	57
ARTotal Emp	6

	AG	AR	AG/AR	AR/AG	
Decision Variables	16.9	0	32.9	6.0	
Weighted Objective	1	1	1000	1000	38940.60

Table 66: "Future", Lower Bound, 5.6, 10%, AG/AR

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum AG Policy	10%

Inputs	
AG Total Hours	23190.51
AR Total Hours	11341.39
AG Total Emp	57
ARTotal Emp	6

	AG	AR	AG/AR	AR/AG
Decision Variables	0.0	0	19.6	7.8

	AG	AR	AG/AR	AR/AG	
Weighted Objective	1	1	1000	1000	27406.27

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 67: "Future", Average, 5.6, 10%, AG/AR

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum AG Policy	10%

Inputs	
AG Total Hours	28060.36
AR Total Hours	14319.83
AG Total Emp	57
ARTotal Emp	6

	AG	AR	AG/AR	AR/AG	
Decision Variables	0.0	0	23.6	10.0	
Weighted Objective	1	1	1000	1000	33635.07

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 68: "Future", Upper Bound, 5.6, 10%, AG/AR

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260

Inputs	
AG Total Hours	32768.36
AR Total Hours	17515.64
AG Total Emp	57

Minimum AG Policy	10%

ARTotal Emp	6

	AG	AR	AG/AR	AR/AG	
Decision Variables	0.0	0	27.5	12.4	
Weighted Objective	1	1	1000	1000	39907.94

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 69: "Future", Lower Bound, 5.6, 25%, AG/AR

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum AG Policy	25%

Inputs	
AG Total Hours	23190.51
AR Total Hours	11341.39
AG Total Emp	57
ARTotal Emp	6

	AG	AR	AG/AR	AR/AG	
Decision Variables	0.0	0	23.1	4.3	
Weighted Objective	1	1	1000	1000	27406.27

Table 70: "Future", Average, 5.6, 25%, AG/AR

Inputs	
OPMD	5.6

Inputs	
AG Total Hours	28060.36

Work Days	225		AR Total Hours	14319.83
Annual Output	1260		AG Total Emp	57
Minimum AG Policy	25%		ARTotal Emp	6

	AG	AR	AG/AR	AR/AG	
Decision Variables	0.0	0	27.7	5.9	
Weighted Objective	1	1	1000	1000	33635.07

Table 71: "Future", Upper Bound, 5.6, 25%, AG/AR

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum AG Policy	25%

Inputs	
AG Total Hours	32768.36
AR Total Hours	17515.64
AG Total Emp	57
ARTotal Emp	6

	AG	AR	AG/AR	AR/AG	
Decision Variables	0.0	3.697	33.9	2.3	
Weighted Objective	1	1	1000	1000	36214.35

Table 72: "Future", Lower Bound, 5.6, 50%, AG/AR

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260

Inputs	
AG Total Hours	23190.51
AR Total Hours	11341.39
AG Total Emp	57

Minimum AG Policy	50%

ARTotal Emp	6

	AG	AR	AG/AR	AR/AG	
Decision Variables	9.4	0	12.0	6.0	
Weighted Objective	1	1	1000	1000	18011.60

Table 73: "Future", Average, 5.6, 50%, AG/AR

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum AG Policy	50%

Inputs	
AG Total Hours	28060.36
AR Total Hours	14319.83
AG Total Emp	57
ARTotal Emp	6

	AG	AR	AG/AR	AR/AG	
Decision Variables	10.9	0	16.7	6.0	
Weighted Objective	1	1	1000	1000	22740.79

Table 74: "Future", Upper Bound, 5.6, 50%, AG/AR

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum AG Policy	50%

Inputs	
AG Total Hours	32768.36
AR Total Hours	17515.64
AG Total Emp	57
ARTotal Emp	6

AG	AR	AG/AR	AR/AG

Decision Variables	12.1	0	21.8	6.0	
Weighted Objective	1	1	1000	1000	27814.71

Table 75: "Future", Lower Bound, 4.0, 10%, ATAF/ACAD

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum ATAF Policy	10%

Inputs	
ATAF Total Hours	10485.24
ACAD Total Hours	4164.83
ATAF Total Emp	13
ACAD Total Emp	16

	ATAF	ACAD	ATAF/ACAD	ACAD/ ATAF	
Decision Variables	0.0	0	12.5	3.7	
Weighted Objective	1	1	1000	1000	16277.86

Table 76: "Future", Average, 4.0, 10%, ATAF/ACAD

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum ATAF Policy	10%

Inputs	
ATAF Total Hours	12496.58
ACAD Total Hours	4973.48
ATAF Total Emp	13
ACAD Total Emp	16

ATAF	ACAD	ATAF/ACAD	ACAD/ ATAF

Decision Variables	0.0	0	14.9	4.5	
Weighted Objective	1	1	1000	1000	19411.17

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 77: "Future", Upper Bound, 4.0, 10%, ATAF/ACAD

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum ATAF Policy	10%

Inputs	
ATAF Total Hours	15370.27
ACAD Total Hours	5647.01
ATAF Total Emp	13
ACAD Total Emp	16

	ATAF	ACAD	ATAF/ACAD	ACAD/ ATAF	
Decision Variables	0.0	0	18.4	4.9	
Weighted Objective	1	1	1000	1000	23352.54

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 78: "Future", Lower Bound, 4.0, 25%, ATAF/ACAD

Inputs

Inputs

OPMD	4
Work Days	225
Annual Output	900
Minimum ATAF Policy	25%

ATAF Total Hours	10485.24
ACAD Total Hours	4164.83
ATAF Total Emp	13
ACAD Total Emp	16

	ATAF	ACAD	ATAF/ACAD	ACAD/ ATAF	
Decision Variables	4.3	0	8.7	3.3	
Weighted Objective	1	1	1000	1000	11958.96

Table 79: "Future", Average, 4.0, 25%, ATAF/ACAD

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum ATAF Policy	25%

Inputs	
ATAF Total Hours	12496.58
ACAD Total Hours	4973.48
ATAF Total Emp	13
ACAD Total Emp	16

	ATAF	ACAD	ATAF/ACAD	ACAD/ ATAF	
Decision Variables	10.1	0	2.9	6.4	
Weighted Objective	1	1	1000	1000	9292.13

Table 80: "Future", Upper Bound, 4.0, 25%, ATAF/ACAD

Inputs

Inputs

OPMD	4
Work Days	225
Annual Output	900
Minimum ATAF Policy	25%

ATAF Total Hours	15370.27
ACAD Total Hours	5647.01
ATAF Total Emp	13
ACAD Total Emp	16

	ATAF	ACAD	ATAF/ACAD	ACAD/ ATAF	
Decision Variables	0.0	0	22.5	0.9	
Weighted Objective	1	1	1000	1000	23352.54

Note: LP could not be solved using current staffing numbers. The table represents the solution if additional employees could be hired.

Table 81: "Future", Lower Bound, 4.0, 50%, ATAF/ACAD

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum ATAF Policy	50%

Inputs	
ATAF Total Hours	10485.24
ACAD Total Hours	4164.83
ATAF Total Emp	13
ACAD Total Emp	16

	ATAF	ACAD	ATAF/ACAD	ACAD/ ATAF	
Decision Variables	7.0	0	0.0	9.3	
Weighted Objective	1	1	1000	1000	9262.20

Table 82: “Future”, Average, 4.0, 50%, ATAF/ACAD

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum ATAF Policy	50%

Inputs	
ATAF Total Hours	12496.58
ACAD Total Hours	4973.48
ATAF Total Emp	13
ACAD Total Emp	16

	ATAF	ACAD	ATAF/ACAD	ACAD/ ATAF	
Decision Variables	8.4	0	0.0	11.1	
Weighted Objective	1	1	1000	1000	11060.53

Table 83: “Future”, Upper Bound, 4.0, 50%, ATAF/ACAD

Inputs	
OPMD	4
Work Days	225
Annual Output	900
Minimum ATAF Policy	50%

Inputs	
ATAF Total Hours	15370.27
ACAD Total Hours	5647.01
ATAF Total Emp	13
ACAD Total Emp	16

	ATAF	ACAD	ATAF/ACAD	ACAD/ ATAF	
Decision Variables	10.8	0	0.0	12.5	
Weighted Objective	1	1	1000	1000	12559.72

Table 84: "Future", Lower Bound, 5.6, 10%, ATAF/ACAD

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum ATAF Policy	10%

Inputs	
ATAF Total Hours	10485.24
ACAD Total Hours	4164.83
ATAF Total Emp	13
ACAD Total Emp	16

	ATAF	ACAD	ATAF/ACAD	ACAD/ ATAF	
Decision Variables	0.0	0	8.9	2.7	
Weighted Objective	1	1	1000	1000	11627.04

Table 85: "Future", Average, 5.6, 10%, ATAF/ACAD

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum ATAF Policy	10%

Inputs	
ATAF Total Hours	12496.58
ACAD Total Hours	4973.48
ATAF Total Emp	13
ACAD Total Emp	16

	ATAF	ACAD	ATAF/ACAD	ACAD/ ATAF	
Decision Variables	0.0	0	10.7	3.2	
Weighted Objective	1	1	1000	1000	13865.12

Table 86: "Future", Upper Bound, 5.6, 10%, ATAF/ACAD

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum ATAF Policy	10%

Inputs	
ATAF Total Hours	15370.27
ACAD Total Hours	5647.01
ATAF Total Emp	13
ACAD Total Emp	16

	ATAF	ACAD	ATAF/ACAD	ACAD/ ATAF	
Decision Variables	1.3	0	11.7	3.7	
Weighted Objective	1	1	1000	1000	15375.80

Table 87: "Future", Lower Bound, 5.6, 25%, ATAF/ACAD

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum ATAF Policy	25%

Inputs	
ATAF Total Hours	10485.24
ACAD Total Hours	4164.83
ATAF Total Emp	13
ACAD Total Emp	16

	ATAF	ACAD	ATAF/ACAD	ACAD/ ATAF	
Decision Variables	0.0	0	10.8	0.8	
Weighted Objective	1	1	1000	1000	11627.04

Table 88: "Future", Average, 5.6, 25%, ATAF/ACAD

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum ATAF Policy	25%

Inputs	
ATAF Total Hours	12496.58
ACAD Total Hours	4973.48
ATAF Total Emp	13
ACAD Total Emp	16

	ATAF	ACAD	ATAF/ACAD	ACAD/ ATAF	
Decision Variables	0.0	0	12.9	1.0	
Weighted Objective	1	1	1000	1000	13865.12

Table 89: "Future", Upper Bound, 5.6, 25%, ATAF/ACAD

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum ATAF Policy	25%

Inputs	
ATAF Total Hours	15370.27
ACAD Total Hours	5647.01
ATAF Total Emp	13
ACAD Total Emp	16

	ATAF	ACAD	ATAF/ACAD	ACAD/ ATAF	
Decision Variables	6.1	0	6.9	3.7	
Weighted Objective	1	1	1000	1000	10572.37

Table 90: "Future", Lower Bound, 5.6, 50%, ATAF/ACAD

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum ATAF Policy	50%

Inputs	
ATAF Total Hours	10485.24
ACAD Total Hours	4164.83
ATAF Total Emp	13
ACAD Total Emp	16

	ATAF	ACAD	ATAF/ACAD	ACAD/ ATAF	
Decision Variables	5.0	0	0.0	6.6	
Weighted Objective	1	1	1000	1000	6615.86

Table 91: "Future", Average, 5.6, 50%, ATAF/ACAD

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum ATAF Policy	50%

Inputs	
ATAF Total Hours	12496.58
ACAD Total Hours	4973.48
ATAF Total Emp	13
ACAD Total Emp	16

	ATAF	ACAD	ATAF/ACAD	ACAD/ ATAF	
Decision Variables	6.0	0	0.0	7.9	
Weighted Objective	1	1	1000	1000	7900.38

Table 92: “Future”, Upper Bound, 5.6, 50%, ATAF/ACAD

Inputs	
OPMD	5.6
Work Days	225
Annual Output	1260
Minimum ATAF Policy	50%

Inputs	
ATAF Total Hours	15370.27
ACAD Total Hours	5647.01
ATAF Total Emp	13
ACAD Total Emp	16

	ATAF	ACAD	ATAF/ACAD	ACAD/ ATAF	
Decision Variables	7.7	0	0.0	9.0	
Weighted Objective	1	1	1000	1000	8971.23

Appendix 2: Scheduling Theory Output

Scheduling Heuristics

Visual representations of the scheduling heuristics are contained in Figure 2 through Figure 6. The left column contains the type of employees. In our example, we used five fuels (ATAF) technicians and five multi-skilled fuels/avionics (ATAF/ACAD) technicians. The first row indicates the time in hours, ranging from 0 – 60 hours. The blocks indicate jobs (operation numbers from PDMSS are included within). Blue jobs are fuels jobs and can be performed by either the ATAF or ATAF/ACAD technician. Yellow jobs are avionics jobs and can only be performed by the ATAF/ACAD technicians.

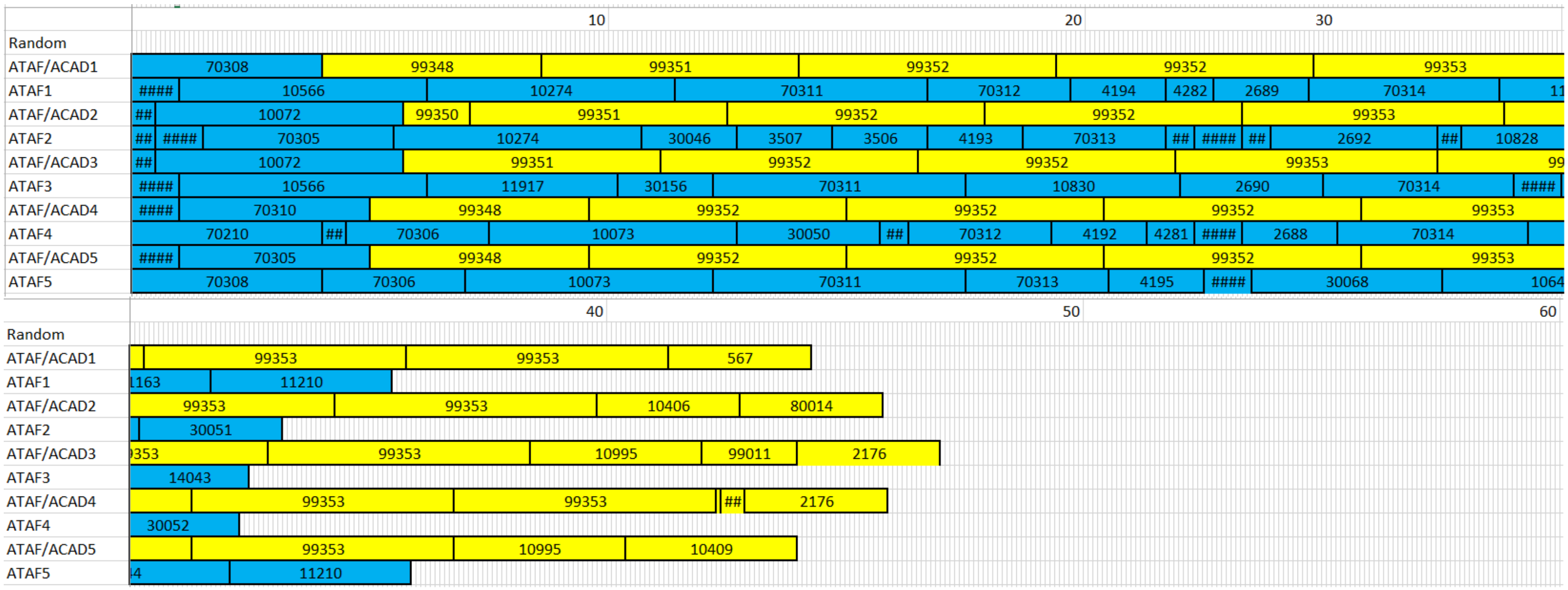

Figure 2: Scheduling, Random

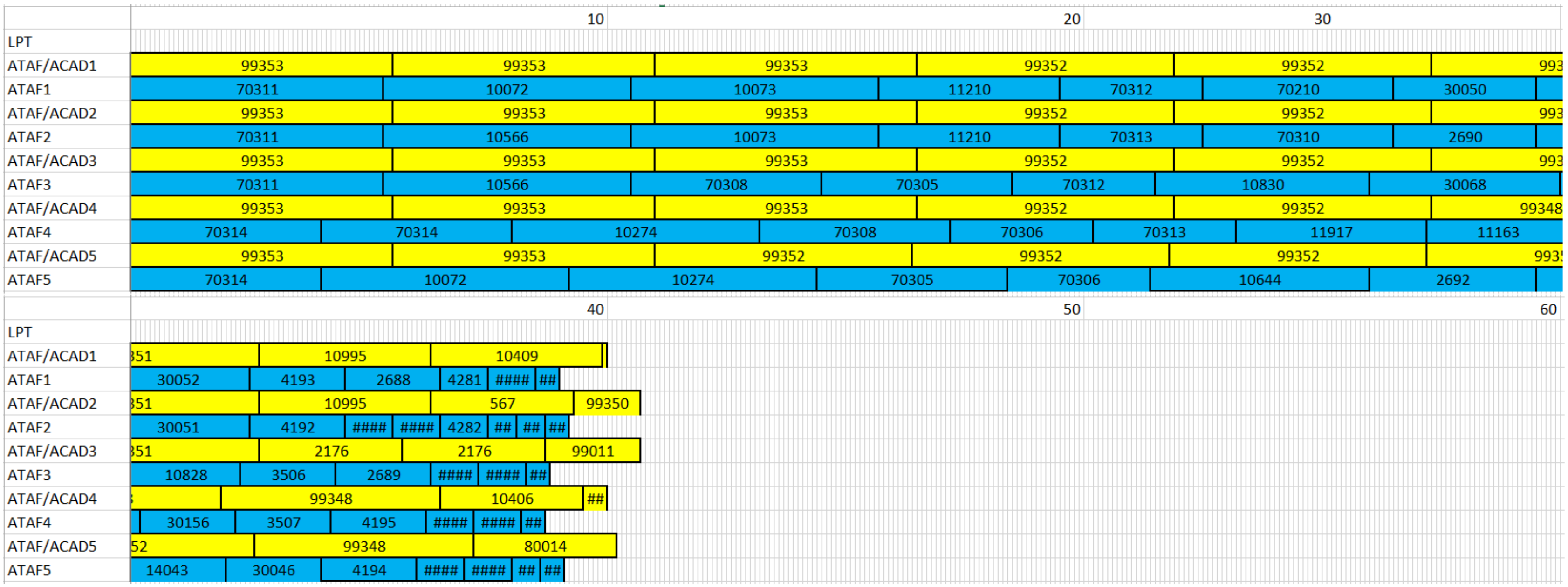

Figure 3: Scheduling, LPT

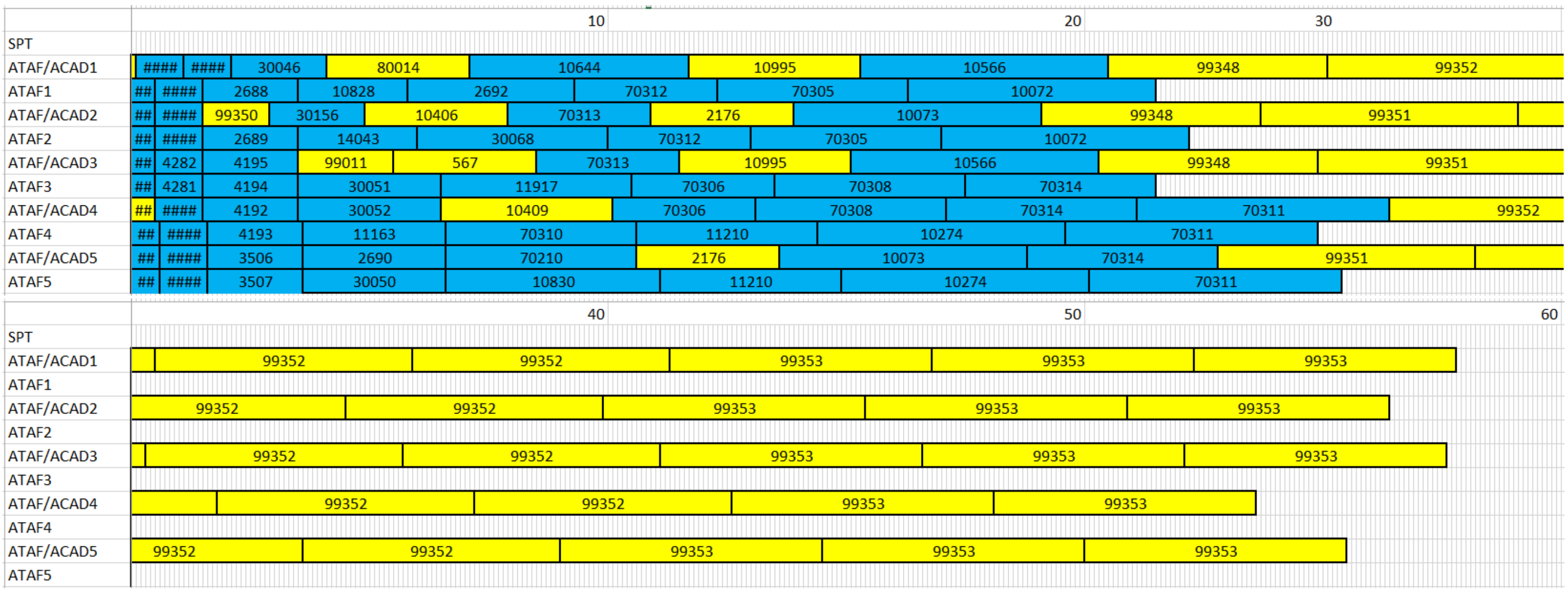

Figure 4: Scheduling, SPT

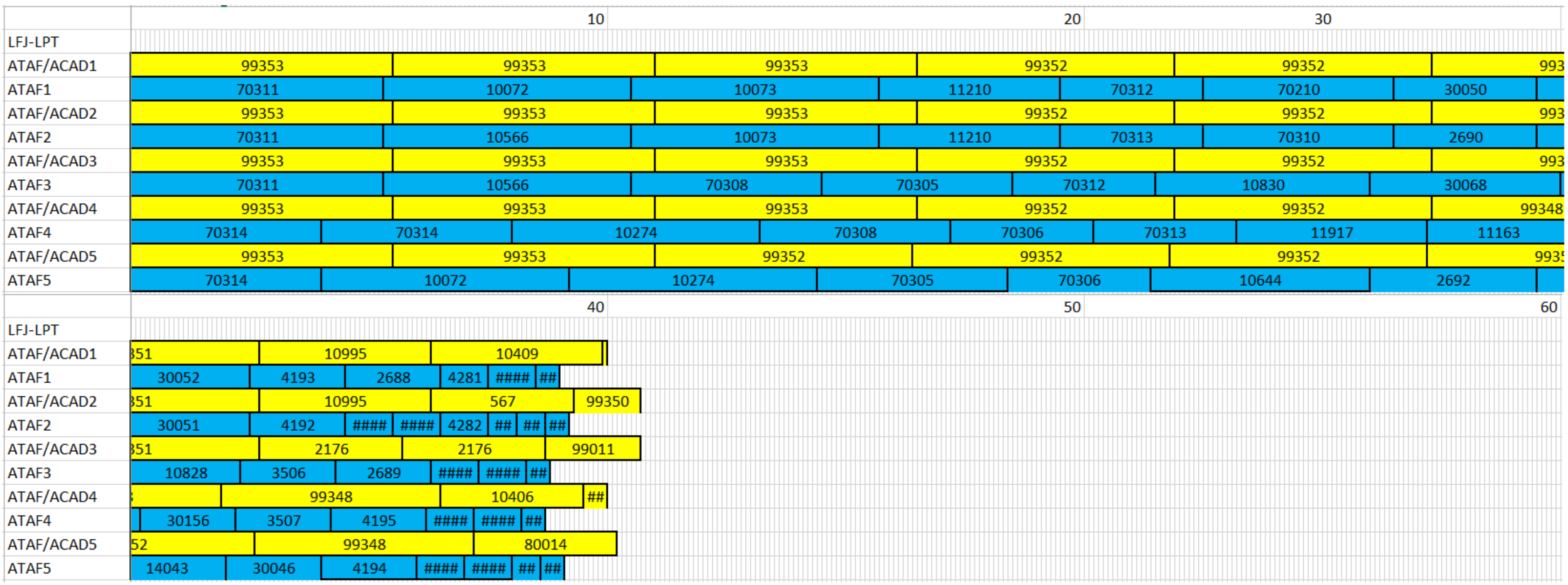

Figure 5: Scheduling, LFJ-LPT

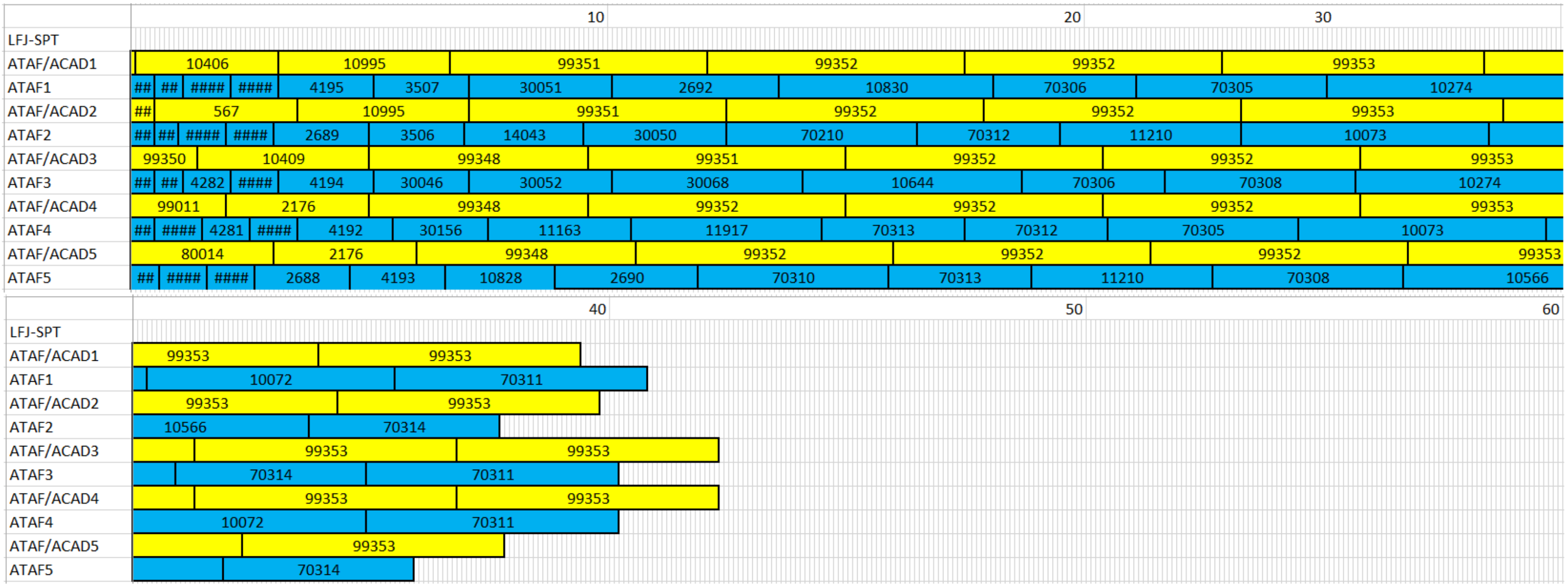

Figure 6: Scheduling, LFJ-SPT

Appendix 3: Thesis Storyboard

OVERCOMING HURDLES IMPLEMENTING MULTI-SKILLING POLICIES

Capt Joshua Isom
Advisor: Dr. Alan Johnson
Member: Dr. Kenneth Schultz
Department of Operational Sciences (ENS)
Air Force Institute of Technology

INTRODUCTION

Sheppard (2014) demonstrated the benefits of multi-skilling in a simulated environment by modeling the F-22 Heavy Maintenance Modification Program at Ogden ALC. These benefits include cost savings/avoidance estimated at > $1.1 million, increased employee utilization and reduced flow days for aircraft. This research sought to continue that research to help make multi-skilling possible.

THE PROBLEM

Authorization to multi-skill with promotion incentives via the 2013 National Defense Authorization Act (NDAA) is set to expire at the end of Fiscal Year 2018. There exist several hurdles to implementation that this research investigated.

METHODOLOGY

Linear Programming was used to make staffing decisions given multiple constraints. Scheduling theory was applied to give supervisors an easy to use heuristic to make effective use of the new multi-skilled workforce.

$$
\begin{array}{llllllllll}
\text{MAX:} & 1\,X_1 & + & 1\,X_2 & + & 1000\,X_3 & + & 1000\,X_4 & & (1)\\
\text{Subject to:} & a_{11}\,X_1 & + & 0\,X_2 & + & a_{13}\,X_3 & + & a_{14}\,X_4 & = b_1 & (2)\\
 & 0\,X_1 & + & a_{22}\,X_2 & + & a_{23}\,X_3 & + & a_{24}\,X_4 & = b_2 & (3)\\
 & 1\,X_1 & & & + & 1\,X_3 & & & \le b_3 & (4)\\
 & & & 1\,X_2 & & & + & 1\,X_4 & \le b_4 & (5)\\
 & 1\,X_1 & & & & & & & \ge 0 & (6)\\
 & & & 1\,X_2 & & & & & \ge 0 & (7)\\
 & & & & & 1\,X_3 & & & \ge 0 & (8)\\
 & & & & & & & 1\,X_4 & \ge 0 & (9)
\end{array}
$$

Table 19: Summary, Current State Average Workload

	AP/AS	AG/AR	ATAF/ACAD	Total
4.0 OPMD Avg Workload	313.9 AP/AS Technicians	47.1 AG/AR Technicians	19.41 ATAF/ ACAD Technicians	380.41 Technicians
5.6 OPMD Avg Workload	224.20 AP/AS Technicians	33.64 AG/AR Technicians	13.87 ATAF/ ACAD Technicians	271.71 Technicians

Table 20: Scheduling Results

	Random	LPT	SPT	LFJ-LPT	LFJ-SPT
Makespan	47 hours	40.7 hours	57.9 hours	40.7 hours	42.4 hours

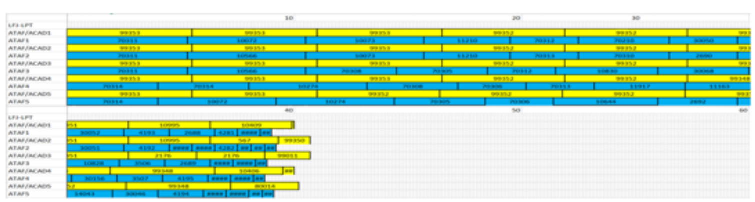

Figure 5: Scheduling, LFJ-LPT

RESEARCH OBJECTIVES

1. How many employees can you multi-skill and still maintain a minimum level of proficiency?
2. Once multi-skilled, is there a technique to assist in effectively scheduling the workforce?

Results and Conclusions

1. Initial skills training presents several opportunities to mitigate against skill loss over retention intervals, as well as help with skills transfer from the training environment to on the job.
2. 100 percent multi-skilled is not achievable without risking the proficiency of the workforce. Recommendations for staffing provided in thesis.
3. Least Flexible Job (LFJ) with Longest Processing Time first (LPT) is an easy to use heuristic that provides a significant reduction in time to complete tasks.

Future Research

1. Behavioral study on the skill pairing choices and their implications on output
2. Measured skill loss study to further modify staffing and strategies to obtain a further efficient workforce.

DEPARTMENT OF OPERATIONAL SCIENCES

Bibliography

108th Congress. *National Defense Authorization Act for Fiscal Year 2004*. (24 November 2003).
http://www.gpo.gov/fdsys/pkg/PLAW-108publ136/pdf/PLAW-108publ136.pdf

110th Congress. *National Defense Authorization Act for Fiscal Year 2008*. (6 December 2007).
http://www.gpo.gov/fdsys/pkg/CRPT-110hrpt477/pdf/CRPT-110hrpt477.pdf

112th Congress. *National Defense Authorization Act for Fiscal Year 2013*. (3 January 2012).
http://www.gpo.gov/fdsys/pkg/BILLS-112hr4310enr/pdf/BILLS-112hr4310enr.pdf

Arthur, Jr., Winfred, Eric A. Day, Winston Bennett, Jr., Theresa L. McNelly, and Jeffrey A. Jordan. "Dyadic Versus Individual Training Protocols: Loss and Reacquisition of a Complex Skill." *Journal of Applied Psychology* 82(5): 783-791 (1997).

—. “Factors That Influence Skill Decay and Retention: A Quantitative Review and Analysis.” *Human Performance* 11(1): 57-101 (1998).

Baldwin, Timothy T. and J. K. Ford. “Transfer of Training: A Review and Directions for Future Research.” *Personnel Pyschology* 41(1): 63-105 (Spring 1988).

Driskell, James E., Ruth P. Willis and Carolyn Copper. "Effect of Overlearning on Retention." *Journal of Applied Psychology* 77(5): 615-622 (1992).

Elliot, Ronald G. “Project Rivet Workforce and the Air National Guard.” Air War College, Maxwell AFB AL (1988). (ADA194895)

Hatala, John-Paul and Pamela R. Fleming. "Making Transfer Climate Visible: Utilizing Social Network Analysis to Facilitate the Transfer of Training." *Human Resources Development Review* 6(1): 1-31 (2007).

Hurlock, Richard E. and William E. Montague. *Skill Retention and its Implications for Navy Tasks: An Analytical Review: Technical Report, September 1979 – September 1980.*. San Diego CA: Navy Personnel Research and Development Center (April 1982). (ADA114211)

Lewis, Catherine. “Linear Programming: Theory and Applications.” (11 May 2008).
https://www.whitman.edu/mathematics/SeniorProjectArchive/2008/lewis.pdf

Lewis, Keith A. *A Study on the Air Force's Ability to Field Senior Logistics Readiness Officers Experienced in Fuels Management*. MS thesis, AFIT/GLM/ENS/05-14. Graduate School of Engineering and Management, Air Force Institute of Technology (AU), Wright-Patterson AFB OH (March 2005). (ADA431493)

Martin, Harry J. "Workplace Climate and Peer Support as Determinants of Training Transfer." *Human Resource Development Quarterly* 21(1): 87-104 (Spring 2010).

O'Neill, Kevin. *Sustaining the US Air Force's Force Support Career Field through Officer Workforce Planning*. PhD dissertation. Pardee RAND Graduate School, Santa Monica CA (2012). http://www.rand.org/content/dam/rand/pubs/rgs_dissertations/2012/RAND_RGSD302.pdf

Pinedo, Michael L. *Scheduling: Theory, Algorithms, and Systems* (4th Edition). New York: Springer (2012).

Pinker, Edieal J. and Robert A. Shumsky. "The Efficiency-Quality Trade-Off of Cross-Trained Workers." *Manufacturing & Service Operations Management* 2(1): 32-48 (2000).

Ragsdale, Cliff T. *Spreadsheet Modeling & Decision Analysis* (5th Edition). Mason OH: South-Western (2008).

Schendel, Joel D. and Joseph D. Hagman. *On Sustaining Procedural Skills Over Prolonged Retention Intervals*. Alexandria VA: US Army Research Institute for the Behavioral and Social Sciences (Jul 1980). (ADA120758)

Schindler, Laura A. *A Mixed Methods Examination of the Influence of Dimensions of Support on Training Transfer*. PhD dissertation. Walden University, Minneapolis MN (2012).

Sheppard, Wesley A. *Simulating F-22 Heavy Maintenance and Modifications Workforce Multi-Skilling*. MS thesis, AFIT-ENS-14-M-28. Graduate School of Engineering and Management, Air Force Institute of Technology (AU), Wright-Patterson AFB OH (March 2014).

SWA Consulting, Inc. *Examine the Impact of Training Duration on Retention*: *Technical Report, September 2012*. Contract H92222-10-D-0017/0007. Macdill AFB FL: HQ USSOCOM, Special Operations Forces Language Office (September 2012). (ADA585075)

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14. ABSTRACT Ogden ALC at Hill AFB has been authorized to promote wage grade employees if they are multi-skilled, but that authorization will expire at the end of Fiscal Year 2018. Simulation research by Capt Wesley Sheppard demonstrated significant cost savings/cost avoidance if multi-skilling is pursued, but there are significant challenges to implementation. This research examined two challenges in implementation. First, how many employees can be multi-skilled and still maintain proficiency in both skills? Second, once multi-skilled, is there a technique that can be applied to easily and effectively schedule the new multi-skilled workforce. Using linear programming, staffing numbers were calculated based on current manning and a minimum time policy to ensure the multi-skilled workforce has the opportunity to perform both skills. These calculations were based on a variety of inputs, such as output per man day (OPMD), different minimum time policies, an estimated lower bound, average, and upper bound for the annual workload, etc. Scheduling theory was applied to give schedulers and front line supervisors an easy to use heuristic that can make a significant difference in the amount of time it takes to complete a set of tasks. Various scheduling heuristics were applied to give supervisors an effective way to schedule the workforce.			
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